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16. Abstract

An investigation was conducted to develop qualification requirements which reliably duplicate the service performance of rail fasteners. The study included a review of available data from qualification tests, measurements of rail/tie deflections and fastener clip strains at the Facility for Accelerated Service Testing (FAST), and laboratory tests at Battelle which simulated the FAST environment. Several aspects of service performance at FAST were successfully duplicated in the laboratory tests. Recommendations are made for the design of improved fastener qualification tests.

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METRIC EQUIVALENTS OF ENGLISH UNITS USED IN THIS REPORT

Multiply the English Unit		by	To obtain the Metric Unit	
Basic Units:				
Foot	(ft)	0.3048	Meter	(m)
Inch	(in)	25.4	Millimeter	(mm)
Pound (force)	(lb)	4.4482	Newton	(N)
Degrees Fahrenheit	(°F)	5/9 (F - 32)	Degrees Celcius	(C)
Combined Units				
Kip = 1000 lb	(kip)	0.3048	Kilonewton	(kN)
Foot-Pound	(ft-lb)	1.3358	Joule = Watt-Sec.	(J)
Pound/Inch	(lb/in)	1.751	Newton/millimeter	(N/mm)
Strain	(μin/in)	1	Strain	(μm/m)

PREFACE

This report completes an investigation to identify improvements in performance requirements for rail fasteners used in U.S. mainline service. Battelle Columbus Laboratories conducted the study under Contract DOT-FR-9162 entitled "Tie and Fastener Verification Studies." The overall program was sponsored by the Improved Track Structures Research Division of the Federal Railroad Administration (FRA). In a related phase of the same program, Battelle investigated the effects of tie pad stiffness on the attenuation of dynamic loads in concrete ties installed on the Northeast Corridor track.

Mr. Howard G. Moody of the FRA served as the Contracting Officer's Technical Representative and contributed significantly to this effort by obtaining timely delivery of test materials and by editing the suggestions of the reviewers in preparation of the final draft. Several representatives of railroads and suppliers provided meticulous reviews of the draft report. The efforts of all of these people are greatly appreciated.

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INTRODUCTION

This investigation was conducted to identify potential improvements in performance requirements for rail fasteners. Improvements are needed to reduce the greater tie and fastener maintenance demands which have emerged with increased levels of lateral and vertical track loading.

Maintenance problems on highly loaded wood tie track (tie plate cutting and spike killing of the ties, rapid deterioration of surface and alignment) have led to two developments: (1) the trial use of nonconventional fasteners on wood ties, and (2) the introduction and expanding use of concrete ties. While some of the new systems have brought improvements in the critical area of gauge widening, many have experienced additional problems. These include the failure of components (concrete tie fastener clips, tie pads and insulators, wood tie plates and holddown spikes), the lack of adequate longitudinal restraint, and the cracking of concrete ties.

Performance specifications for concrete tie fasteners have been developed by several railway associations and rail transit authorities. In most cases, the specifications require a series of qualification tests in which the fastener system is subjected to static and dynamic loads. The retention of fastener strength and resistance to permanent deformation are determined by static measurements before and after fatigue tests. While such tests have served to differentiate among candidate systems, they have often not provided reliable indications of performance in track. The value of the tests is limited by a lack of information about the fastener service environment.

To develop fastener performance requirements which better represent the service environment, a research program was carried out in the following phases:

a. A review of fastener performance problems, existing performance requirements and available data from laboratory tests was conducted. This review is presented in Reference [1].

b. To define a representative fastener loading environment, a field test program was carried out at the Facility for Accelerated Service Testing (FAST). Measurements of rail/tie deflection and fastener clip strains were made on 5-degree curves of wood and concrete tie track. Results of the field measurements and supporting laboratory tests are reported in Reference [2].

c. A laboratory study was conducted to:

(1) define more realistic fastener fatigue tests. This was accomplished by subjecting two of the

fastener systems to simulated service environments (based on the measured fastener deflections and strains) and comparing the results with observed performance at FAST.

(2) improve the determination of basic fastener performance characteristics. These included the fastener yield load and the stiffness of a concrete tie pad.

This report summarizes the preliminary review, presents the essential results of the field measurements at FAST, and describes the subsequent laboratory tests. On the basis of this investigation, recommendations are made for changes to current qualification tests of concrete tie fasteners. If adopted, the changes will provide for:

a. more realistic tests of fastener resistance to fatigue loads

b. the definition of pad stiffness over the range of pad loads expected in service

c. elmination or simplification of other tests used in the current specifications.

Review of Fastener Performance Problems

Wood Tie Fasteners

The conventional wood tie fastener in U.S. service consists of:

a. a tie plate to transfer loads from the rail to the tie

b. cut spikes to constrain the plate and rail against gauge widening and to constrain the rail against rollover

c. rail anchors--spring steel clamps which, when attached to the rail base, constrain longitudinal rail-to-tie movement.

Vertical uplift motion of the rail is allowed through the development of free play between the rail base and the rail line spikes. The amount of free play is adjusted naturally as the rail deflects upward in front of the passing wheels and the line spikes yield slightly from their original anchorage in the tie. Tie pumping is held to a minimum by this development of free play.

This basic fastener has been in use for many years and remains predominant in U.S. track. However, the introduction of 100-ton cars with roller bearings and long unit trains has caused rapid gauge widening, tie plate cutting and spike killing of ties with the conventional fastener. Wear begins in the form of spike pullout and enlargement of spike holes, causing lateral yielding of the tie plate and rotation of the rail. Often the track must be regauged by plugging or filling the spike holes and redriving the spikes. The process accelerates with repeated maintenance and eventually necessitates tie replacement. Finally, frequent transposing and relaying of rail on curves require removal of the line spikes and contribute to spike killing.

Various modifications of the conventional fastener have been introduced to alleviate these problems. These include:

a. additional spikes

b. additional spikes with larger tie plates

c. special screw or locking type spikes as holddown fasteners.

Some railroads have installed test sections of wood tie fasteners, which represent a major departure from the conventional plate-and-spike fastener system. Examples are shown in Figure 1.

The greatest departure from conventional design consists of the use of elastically deforming clips to constrain the rail. The clips may be detachable from the tie plate, may be anchored through the plate by screw spikes or other holddown devices, or may be integral with or permanently fixed to a pair of spikes. One major objective in the use of such clips is to eliminate rail anchors. Wood tie fastener test data shown later indicate that some fastener designs actually exceed the longitudinal restraint of rail anchors, but to date this has not been verified in the field.

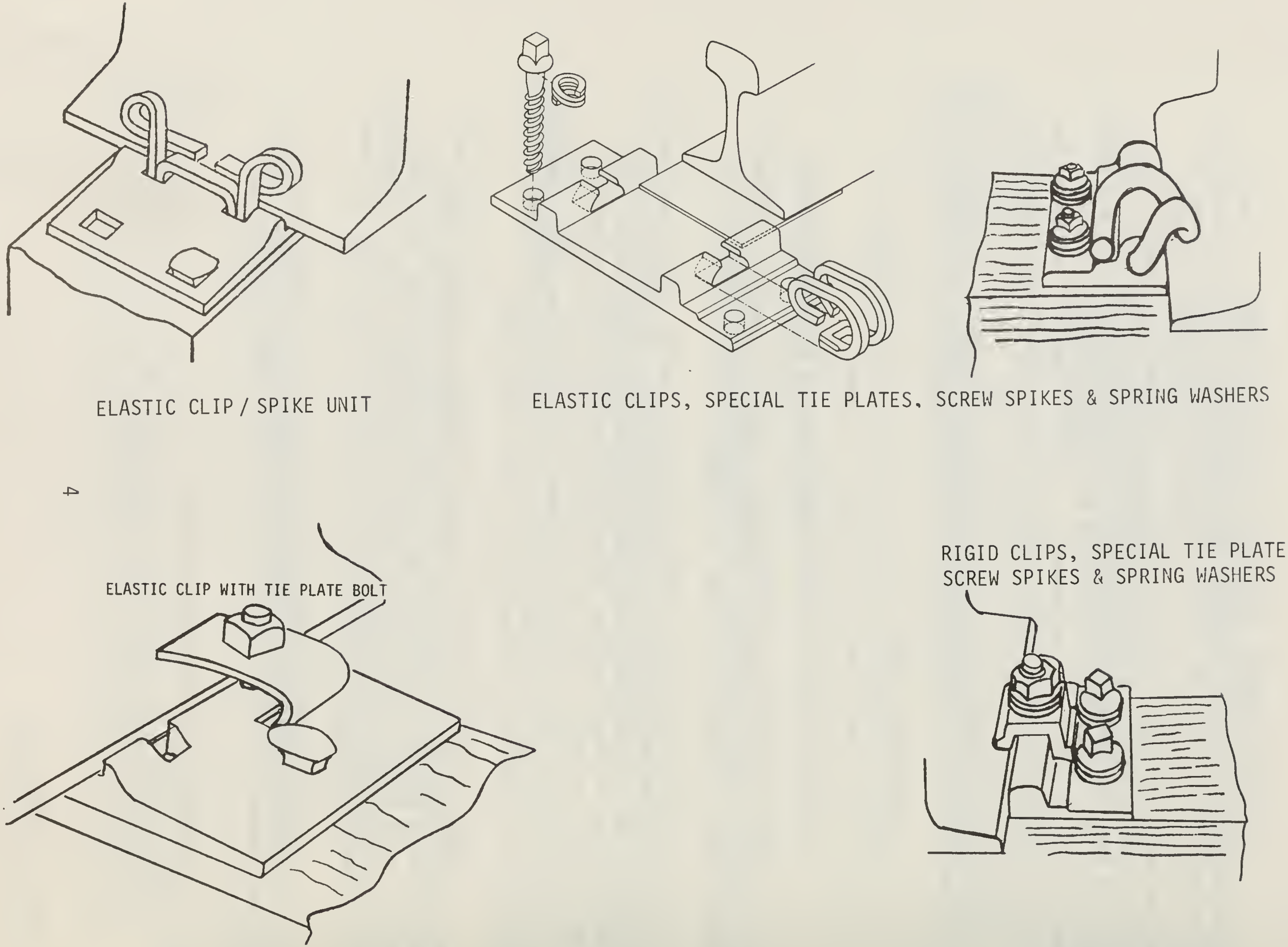
Rigid clip designs have also been introduced. Some of these provide a gap between the clip and the rail base to permit rail uplift and thereby reduce pumping. Since the gap eliminates longitudinal restraint by the clip, rail anchors are required. However, detachable clips of either the rigid or elastic type have a major advantage in that the rail can be transposed or replaced without respiking.

Tests of nonconventional wood tie fasteners in revenue service have provided early evidence of improved performance [3]. However, tests at FAST under severe and accelerated conditions have produced the following problems [4]:

a. elastic clips broken or loose

b. tie plates broken at clip attachments

[ ] Refer to References



ELASTIC CLIP / SPIKE UNIT

ELASTIC CLIPS, SPECIAL TIE PLATES, SCREW SPIKES & SPRING WASHERS

ELASTIC CLIP WITH TIE PLATE BOLT

RIGID CLIPS, SPECIAL TIE PLATE,
SCREW SPIKES & SPRING WASHERS

FIGURE 1. EXAMPLES OF NONCONVENTIONAL WOOD TIE FASTENERS

c. screw spikes broken off in the tie

d. spikes pulled out.

Concrete Tie Fasteners

Fastening systems for concrete ties generally consist of:

a. a pair of detachable clips, either elastic or rigid

b. clip anchorages or shoulders either embedded in the concrete or inserted into a threaded sleeve

c. a pair of insulators in the form of separate pieces inserted between the clip and the rail or of material bonded to the fastener shoulders

d. a pad of elastomeric, rubber or composite material to provide vertical resilience and prevent tie abrasion.

Examples of concrete tie fasteners are shown in Figure 2.

Problems identified at FAST and in revenue service test segments of concrete ties have included:

a. dislocation, fall-out and fracture of elastic clips (primarily at the inside-gauge position of the FAST Section 17 five-degree curve)

b. cracking, dislocation and deterioration of pads and insulators

c. excessive tie skewing

d. shoulder loosening (Northeast Corridor).

Problems in skewing of concrete ties are aggravated by the fact that rail anchors are not commonly part of the fastener system except where rigid clips are used with a clip-to-rail gap. However, rail anchors were introduced at FAST to prevent skewing and bunching at the bottom of a 2-percent grade in the 5-degree curve of Section 17. Since concrete tie fastener systems are already very expensive, it is expected that rail anchors would only be used in the most severe loading environments.

There is one major performance problem which is peculiar to concrete tie track. Concrete tie construction creates a track with much higher vertical stiffness than does wood tie construction on a similar roadbed. This must be compensated by the resilience of the rail pad. The Japanese National Railway (JNR) has determined that for its service requirements, this vertical stiffness must be maintained below rather restrictive levels to prevent excessive ballast settlement, ballast particle degradation, growth of rail corrugations and transmission of noise into the passing vehicle [5,6].

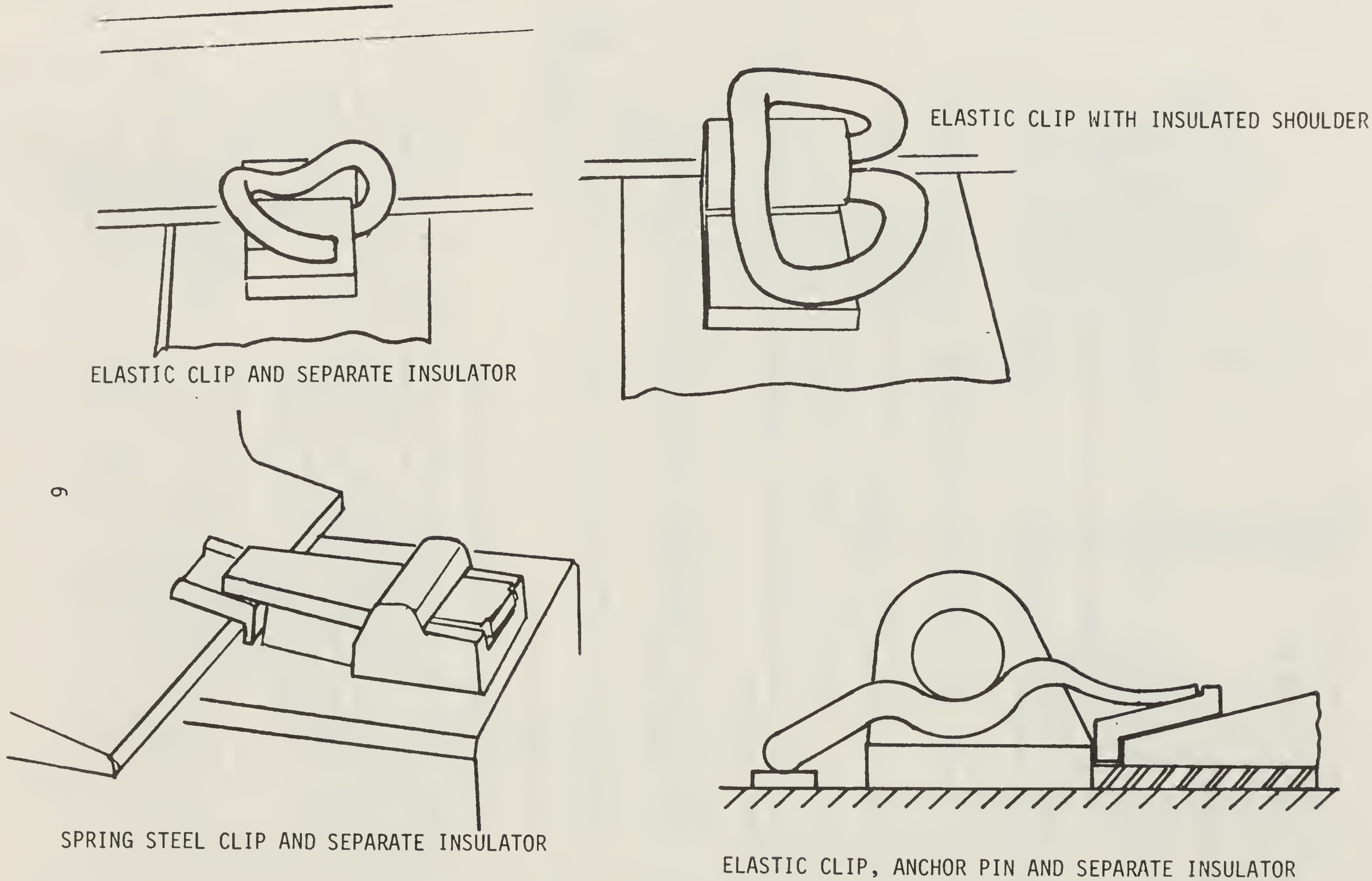


FIGURE 2. EXAMPLES OF CONCRETE TIE FASTENERS

Low vertical stiffness on concrete tie track can only be attained with a pad specifically designed for this purpose. However, many soft pads (stiffness about 500,000 - 1,000,000 pounds/inch) are less durable than harder alternatives (stiffness about 3-5 million pounds/inch). This conflict between requirements for low stiffness vs. durability constitutes one of the principal challenges in the production of cost-effective concrete tie fasteners.

The continued occurrence of service performance problems for the improved, or nonconventional, designs of wood and concrete tie fasteners indicate the need for the development of laboratory tests which can predict performance to be expected in the field.

FASTENER PERFORMANCE SPECIFICATIONS

Chapter 10 of the AREA manual [7] provides specifications for concrete ties and fasteners. Other agencies and railroads, most notably Amtrak, have incorporated the basic AREA fastener tests into an expanded set of requirements which feature the sequenced repetition of several tests [8]. In Table 1 the performance tests of both the AREA and Amtrak specifications are summarized and compared. Table 2 defines the testing sequence of the Amtrak specification.

Both specifications require static and dynamic tests on the fastener systems and components to determine the following characteristics:

a. Strength of the fastener anchorage

b. Resistance to permanent deformation after cycling through compression and uplift loads

c. Resistance to fatigue loading

d. Longitudinal strength against rail creep after the application of cyclic loads

e. Stiffness against gauge widening and rail rollover under vertical and lateral loads

f. Vertical resilience

g. Electrical impedance.

Other than the requirements of the FRA Track Safety Standards in the maintenance of track geometry limits, there are no performance specifications for wood tie fasteners. Chapter 5 of the AREA manual specifies requirements for the strength and durability of plates and spikes. However, it is the interaction of these components with the tie which causes most wood tie problems. Since many nonconventional wood tie fastener components are also used on concrete ties, their design is affected by specifications for concrete tie fasteners.

TABLE 1. SUMMARY OF AREA AND AMTRAK FASTENER PERFORMANCE SPECIFICATIONS

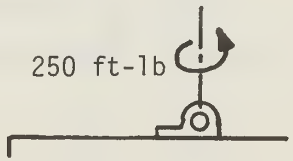
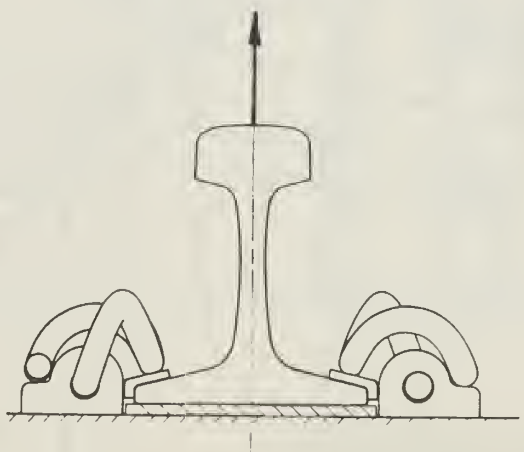
TEST	PROCEDURE	REQUIREMENTS
1. FASTENING INSERT TEST (a) Pullout Test  	AREA: Apply vertical load of 12 kips and hold at least 3 minutes AMTRAK: *Same*	No slippage of insert. No permanent deformation of insert. No cracking of concrete. *Same*
(b) Torque Test  	AREA: Apply torque of 250 ft-lb and hold at least 3 minutes. AMTRAK: *Same*	No rotation or permanent deformation of insert. No cracking of concrete. *Same*
2. FASTENING UPLIFT TEST P = Pad Separation Load 	AREA: Determine rail/pad separation load P. Release load. Apply max load of 1.5P, up to 10 kips. AMTRAK: *Deflect rail in increments of .001 inch until rail/pad separation is reached.* *Apply additional deflection to produce 0.1 inches total.* *Measure load each .01 inch.* *There are 3 repetitions of test in complete sequence.*	No pullout or loosening of insert. No fracture of any component. No rail release. *Spring rate of fastener system must lie between 200,000 and 900,000 lb/in for loads between 0 and 1800 pounds.* *After load release, rail must return within .001 inch of original position.* *Values obtained on repeat tests must fall within 20 percent of original values.* *No slippage, yielding or fracture of any component.*

TABLE 1 (CONT.) SUMMARY OF AREA AND AMTRAK FASTENER PERFORMANCE SPECIFICATIONS

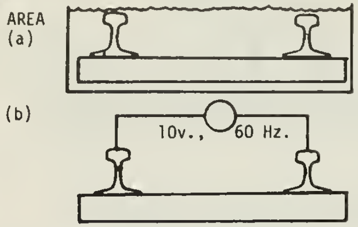
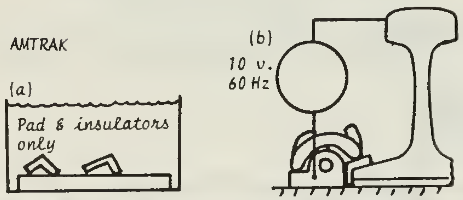
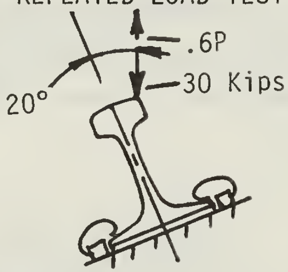
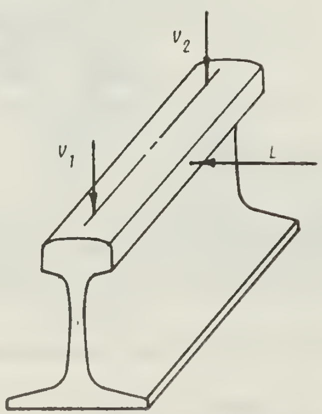
TEST	PROCEDURE	REQUIREMENTS
3. ELECTRICAL IMPEDANCE TEST  	AREA: Immerse complete tie/fastener assembly for 6 hours in water. Within 1 hour after removal, apply 10 v., 60 Hz. for 15 min. Measure rail-to-rail resistance.	Resistance at least 20 K-Ohm.
	AMTRAK: *Immerse insulators and tie pads in deionized water for 8 hours at 100 degrees F.* *Remove and reinstall fastener assembly.* *Within 1 hour, apply 10 v, 60 Hz between head & insert for 15 min. Measure resistance.*	*Resistance at least 20 K-Ohm.*
4. FASTENING REPEATED LOAD TEST AREA 	AREA: Define rail/pad separation load P. (Can use results of Test 2.) Apply 3 million cycles of .6P ↑, 30 Kips ↓. Pad temperature less than 140 F.	No rupture of any component.
AMTRAK 	AMTRAK: *Apply 3 million cycles of 30 Kips ↓, 4 Kips ↑, in the following sequence* V_1 V_2 L *(Kips)* 0 0 0 7.5 4.5 - 15 15 10 4.5 7.5 - 0 0 0 -2 -2 0 *Pad temperature less than 140 F.*	*No rupture of any component.* *No yielding or fracture of any component.* *No slippage of clip or pad greater than 1/4".*

TABLE 1 (Cont.) SUMMARY OF AREA AND AMTRAK FASTENER PERFORMANCE SPECIFICATIONS

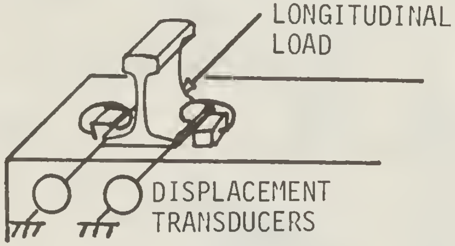
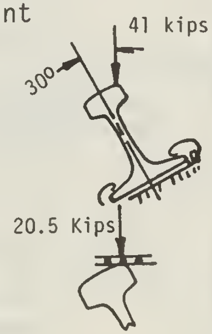
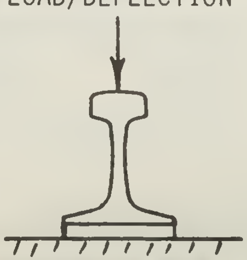
TEST	PROCEDURE	REQUIREMENTS
5. FASTENING LONGITUDINAL RESTRAINT TEST  	AREA: Perform after repeated loads test. Apply 2400 lb. at rail base and hold for 15 minutes. Measure deflection as average of two gage readings. AMTRAK: *Same procedure, except:* *Load is applied at rail center-line instead of rail base.* *There are 3 repetitions of test in complete sequence.*	No slippage greater than 1/4" within 3 minutes. No additional slippage for remainder of 15 minutes. *Same requirements.*
6. LATERAL LOAD RESTRAINT TEST (a) Lateral Movement (b) Rail Rotation  	(a) AREA: Apply load up to 41 kips, unless rail base movement exceeds 1/8". AMTRAK: *No requirement* (b) AREA: Apply load of 20.5 kips through rollers to eliminate lateral resistance at load point. AMTRAK: *No requirement.*	(a) Rail base movement must be less than 1/8". (b) Difference between rail head and rail base lateral displacements cannot exceed 1/4".
7. TIE PAD LOAD/DEFLECTION TEST 	AREA: No requirement. AMTRAK: *Apply downward load in increments of .1 precompression load, up to twice this load.* *Apply load up to 44 Kips in increments of 1000 lb.* *Measure vertical pad deflection at each load increment.*	*Pad must return to within .001" of original position within 5 seconds of load release.* *Plot load vs. deflection and indicate installed position.*

TABLE 1 (Cont.) SUMMARY OF AREA AND AMTRAK FASTENER PERFORMANCE SPECIFICATIONS

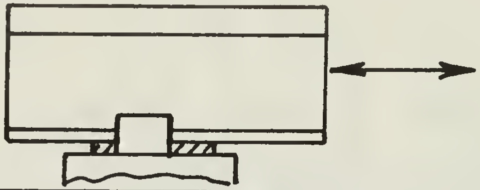
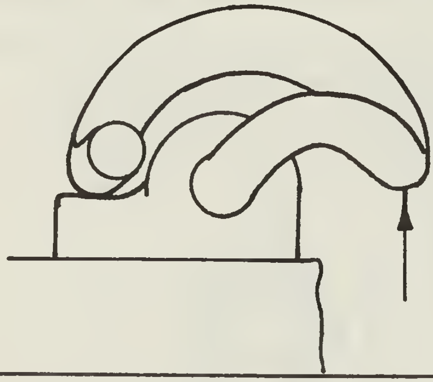
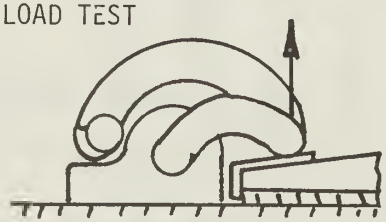
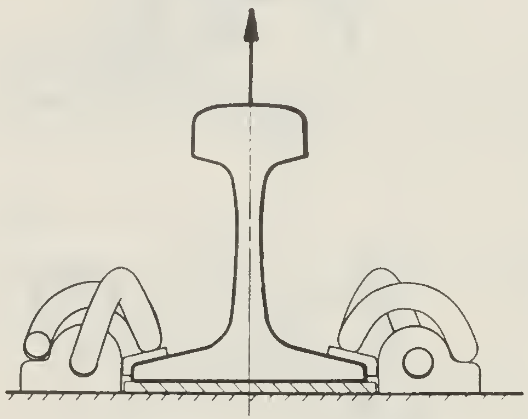
TEST	PROCEDURE	REQUIREMENTS
8. FASTENER PUSH-PULL TEST 	AREA: No requirement. AMTRAK: *Apply 1 million cycles of $\pm$ 2400 lb. longitudinally at rail centroid.*	*No yielding or fracture of any component.*
9. RAIL CLIP LOAD-DEFLECTION TEST 	AREA: No requirement. AMTRAK: *Test all rail clips in fastening assemblies.* *Start at load of 50 lb. Increase load in increments of 200 lb. until .1" past nominal installed deflection. Measure deflection at all load increments.* *Indicate static position on load-deflection plot.* *There are 2 test repetitions in complete sequence.*	*Deflection at nominal installed load, measured after reaching max load, shall be within .001" of deflection during initial load application.* *Slope of load-deflection curve shall be within 20 percent of that found on initial test, for all subsequent test repetitions.*
10. TOE LOAD TEST 	AREA: No requirement. AMTRAK: *Method must assure accuracy within $\pm$ 50 pounds.* *Measure toe loads before and after all other tests.*	*If toe load variation exceeds 5 percent, inspect fastening assembly to determine cause.*

TABLE 1 (Cont.) SUMMARY OF AREA AND AMTRAK FASTENER PERFORMANCE SPECIFICATIONS

TEST	PROCEDURE	REQUIREMENTS
11. FASTENING ASSEMBLY TEST 	AREA: No requirement. AMTRAK: *Read zero displacement with rail unsecured. Secure, measure clip toe loads and installed deflection.* *Apply 44 kips downward, measure toe load and deflection.* *Apply 1.8 kips upward and measure deflection.*	*Compression due to installation of clips shall not exceed 15 % of uncompressed pad thickness.* *44-kip downward load shall not reduce toe load by more than 75 %.* *Deflection due to 44-kip load shall not exceed 15 percent of uncompressed pad thickness.* *1.8-kip uplift load shall not reduce installed compression by more than 75 percent.*

NOTES: AREA test sequence consists of:

a. Tests 1 to 3 applied to a complete tie/fastener assembly.

b. Tests 4-6 applied to a tie block and single fastener assembly.

AMTRAK *test sequence is defined in Table 2.*

TABLE 2. AMTRAK AND AREA FASTENER QUALIFICATION TEST SEQUENCES

(a) Amtrak Sequence

NOTE: Toe load measurements are to be made before and after all tests in the sequence below. Tests will be performed on both rail seats of a tie/fastener assembly. Fastening Insert Test will be performed on one rail seat prior to beginning the sequence.

1. Fastening assembly test
2. Rail clip load/deflection test
3. Tie pad load/deflection test
4. Electrical impedance test
5. Fastening uplift test
6. Fastening longitudinal restraint test
7. Fastening repeated loads test
8. Fastening uplift test
9. Fastening longitudinal restraint test
10. Fastening push-pull test
11. Fastening uplift test
12. Fastening longitudinal restraint test
13. Electrical impedance test
14. Rail clip load/deflection test
15. Tie pad load/deflection test

(b) AREA Sequence

(1) Tests on a Completely Equipped Tie

a. Fastening Insert Test

b. Fastening Uplift Test

c. Electrical Resistance and Impedance Test

(2) Tests on a Tie Block

a. Fastening Repeated Load Test

b. Fastening Longitudinal Restraint Test

c. Fastening Lateral Restraint Test

REVIEW OF EXISTING FASTENER TEST DATA

Available data from the preceding qualification tests and other studies were reviewed to determine the areas where performance improvements appear most needed. Data summary tables are compiled in Appendix A. The major problems indicated by the data are discussed in the following sections.

Rail Clip Force-Deflection Properties

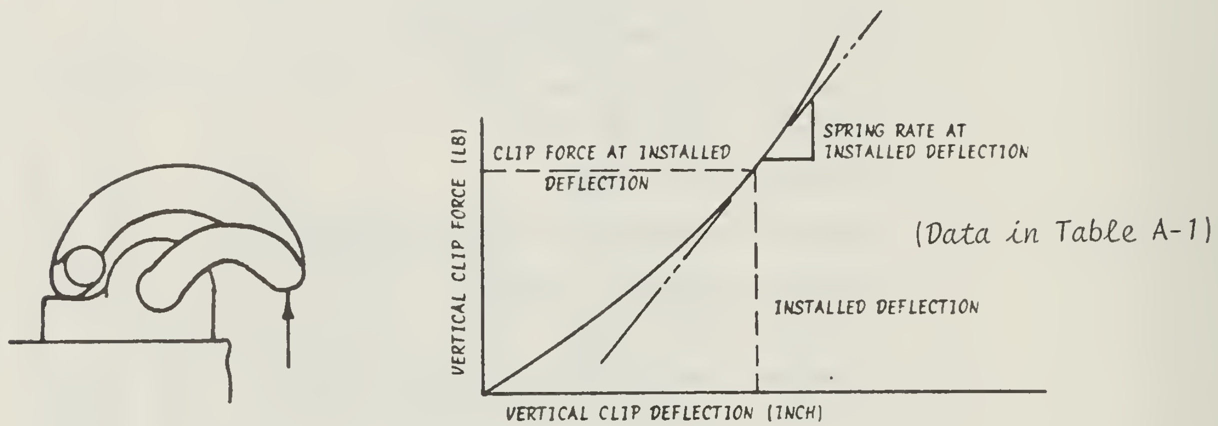


FIGURE 3. CLIP FORCE-DEFLECTION PROPERTIES

A large and uniform clip force (toe load) is required at installed deflection to prevent longitudinal rail/tie creep. Therefore, the nominal clip toe load should be sufficiently below the yield point of the clip to assure that dynamic displacements and construction tolerances will not cause yielding. For two clip designs, clip force-deflection data are available from tests conducted before and after repeated loads tests (Table A-1). Permanent deformation is indicated in both cases by a loss of toe load and a reduction of the clip deflection produced by installation. The results show a definite need to identify the force at which the clip yields and for a criterion which limits the nominal clip toe load to a percentage of yield load.

Tie Pad Stiffness

Figure 4 illustrates two current methods of measuring tie pad stiffness. There is an uplift test requirement in both the AREA and Amtrak series; the Amtrak tests develop a compressive curve up to 44 kips plus the

precompression load but apply no spring rate requirement to it. The compressive spring rate is being used as an index of compressive stiffness for an investigation of the effect of pad stiffness on the attenuation of impact strains in concrete ties [9]. Experience to date indicates that neither of the two methods provides a good predictor of the other. Pad stiffness for either method can vary substantially with load and rate of application.

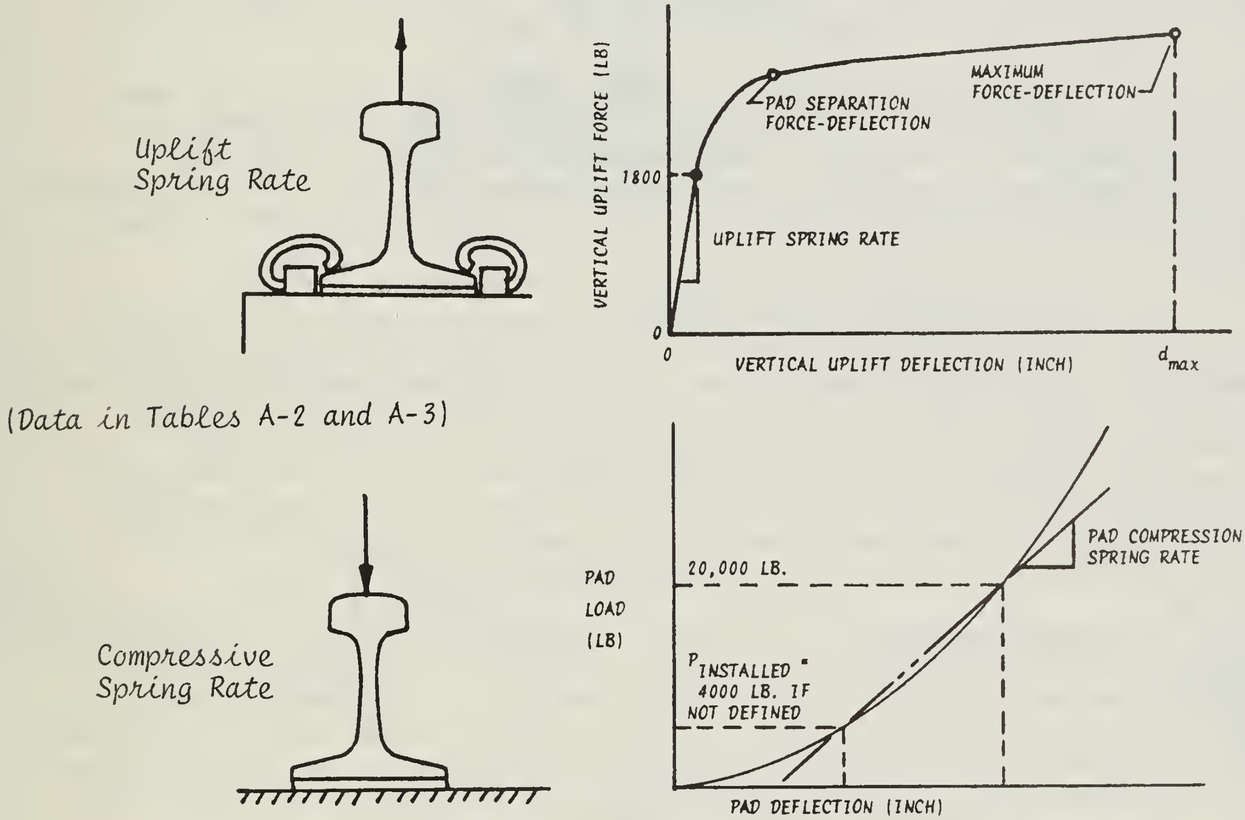


FIGURE 4. TWO METHODS FOR MEASURING TIE PAD STIFFNESS

Several conflicting issues are involved in the selection of an optimum pad stiffness for a given track and traffic. All of the issues involve the compressive load-deflection properties of the pad, either for normal wheel passage or for abnormal wheel load conditions. The issues are:

a. Protection of concrete ties against cracking. Recent discoveries of rail seat cracks in concrete ties on the Northeast Corridor (NEC) and in other revenue service test segments have made protection against cracking an issue. Rail seat cracking occurs where conditions of track support and traffic combine to produce high levels of impact strain in the ties. The

cracks can lead to tie failure. In a concurrent Battelle study, it has been determined that a flexible pad can significantly attenuate impact-produced tie strain [9]. Such pads must have a dynamically measured* compressive spring rate between 500,000 and 1,000,000 lb/in compared with a value of 5 million lb/in for the EVA tie pad currently used on the NEC.

In general, the compressive spring rate of Figure 4 has provided a good indicator of impact strain attenuation. However, where the pad is shaped so that its load-deflection curve turns sharply upward in the region above 10,000 pounds, the attenuation of large impact loads will be much less than expected based on data from the compression test. Therefore, where impact loads are a principal issue, spring rates measured at a high pad load range (40,000 - 50,000 pounds) may be required.

b. Maintenance of ballast support conditions. The JNR [5] has established criteria for tie pad stiffness based on the rate at which surfacing maintenance is required. Its recommended stiffness for the NEC track is approximately one-fifth that of the present NEC pad. The JNR measures stiffness between compressive loads of 1 and 10 metric tons (2200 - 22,000 pounds).

c. Limiting Rail/Tie Deflection. Laboratory tests of pad stiffness vs. rail/tie deflection show a sharp interdependence where tests are conducted on a single fastener system. In this case the bending and torsion of the rail cannot resist the deflection and distribute load to adjacent fasteners. However, the results of measurements on the 5-degree curve of concrete tie track at FAST [2] indicate that pad stiffness may have very little effect on the magnitudes of rail/tie deflections. Although data from other locations are required to verify this finding, it is possible that this issue is much less important than commonly believed.

d. Pad Durability. In general, the hard pad materials (polyethylene, polyurethane, EVA, hard Neoprene) are more resistant to permanent compression, abrasion, and tearing than are most softer materials (soft Neoprene and rubber). The grooving and shaping of pads, which is often required to produce spring rates below 1,000,000 lb/in, may also contribute to pad deterioration, especially where rail rollover causes loading of the pad by the edge of the rail. A grooved pad has less area to resist this concentrated load.

Fastener Longitudinal Restraint

Specifications of longitudinal restraint tests for concrete tie fasteners require the fastener system to sustain 2400 pounds without slip. Data in Table A-4 show that some fastener systems cannot consistently meet this requirement, particularly after being subjected to the repeated loads and push-pull tests of the Amtrak series. In addition, there are indications

* Slope of the load-deflection curve between 4,000 and 20,000 pounds for loading applied at 9-10 cycles per second.

from experience on the South African Railway (SAR) that even higher levels of restraint are required to prevent tie skewing and rail creep under severe conditions in service [10]. The SAR cites a significant improvement in fastener performance when the average toe load was increased from 1800-1900 pounds to 2600 pounds. The longitudinal restraint produced by a pair of clips usually approximates the toe load of a single clip. Figure 5 is a schematic of the method for measuring longitudinal restraint.

(Data in Table A-4)

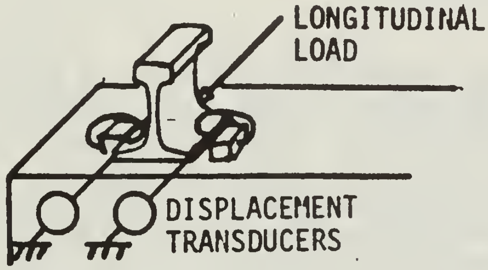
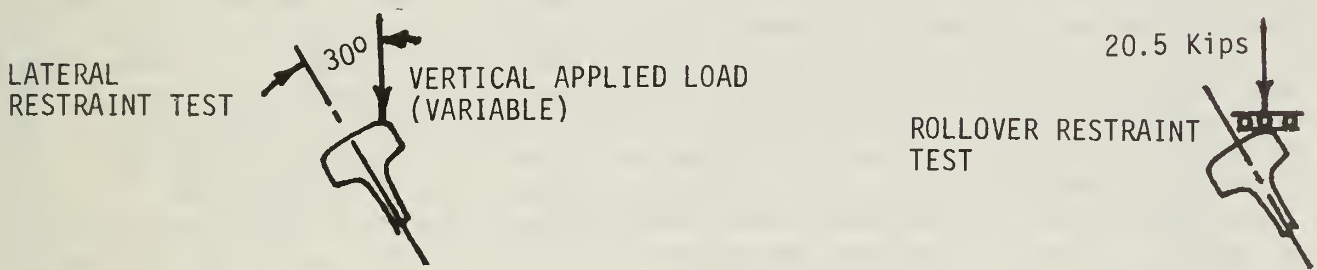


FIGURE 5. MEASUREMENT OF LONGITUDINAL RESTRAINT

Fastener Lateral/Rollover Restraint



(Data in Tables A-5 and A-6)

FIGURE 6. MEASUREMENT OF FASTENER LATERAL AND ROLLOVER RESTRAINT

The final test of the AREA series (No. 6 of Table 1) applies loads (Figure 6) to a rail segment which is mounted on a tie block oriented at an L/V angle of 30 degrees. Lateral displacement of the rail base is limited to 1/8 inch at a load of 41 kips, while the rollover displacement (difference between rail head and rail base lateral displacements) is limited to 1/4 inch at 20.5 kips. The data of Tables A-5 and A-6 show that: (1) the lateral displacement of the rail base was easily constrained by all systems tested, and (2) the rollover displacement requirements were also met by all systems tested, but rollover results were highly dependent on pad stiffness and on the geometry of the rail cross-section. However, the field measurements at FAST (discussed later) show that there is not necessarily a direct dependence between pad stiffness and rail/tie displacement in track.

This test would constitute a determining factor in the qualification of a fastener system only if a clip were to break under the high rollover displacements imposed during the qualification for lateral rail base displacement. This test requires loads up to 41 kips, and Table A-5 shows that it caused rollover displacements up to 0.4 inches. Most clips will yield under much lower displacements [2].

Lateral and Longitudinal Restraint of Wood Tie Fasteners

Table 3 presents results of lateral and longitudinal restraint tests conducted on a 4-tie panel of wood ties. The fastener systems range from the standard 4 cut spikes per plate to several advanced configurations which incorporate elastic or rigid clips and screw or lock spikes. One configuration includes rail anchors on two of the four ties in the panel. Longitudinal restraint loads, developed before the rail slipped by one inch, range from the expected near-zero levels for cut spikes without anchors to 6310 pounds per rail seat for a combination of rigid clips and screw spikes. The configuration with rail anchors produced only 3735 pounds per rail seat. It is significant that 6 of the 8 nonconventional systems without rail anchors produced restraint loads higher than this level, ranging from 7 to 68 percent. However, these results do not reflect the demonstrated loss of restraint loads by clip-type fasteners when installed in track.

To measure lateral restraint, the test panel was subjected to rail-to-rail lateral load until the gauge was widened by 1 inch. An exception was made in the test of the K-fastener, where the test was suspended at a total load of 31,500 pounds with a lateral deflection of 0.58 inches. The deflection was caused by the tie bending rather than by fastener failure. The maximum load was more than three times the load which failed Configuration 1, the standard arrangement of four cut spikes per plate. In contrast to the performance of the K-fastener, five of the nonconventional configurations produced inceases in resistance over the standard fastener ranging from 41 to 64 percent. These values can be compared with a 27 percent addition produced by the addition of a single cut spike.

Figure 7 shows the results of tests conducted in Europe [12] where it was demonstrated that the application of a single static load may be a poor measure of longitudinal restraint under vibration simulating train action. Tests involved a common elastic clip fastener with a hard masonite pad placed over a steel tie plate on a wood tie. A vibrator was attached to the rail to simulate rail vibration in parallel with the statically applied vertical and lateral wheel loads. Results with and without vibration are shown in Figure 7. The vibration had the effect of reducing the mean longitudinal load at the initiation of slip from about 1600 kg to about 800 kg (3500 to 1750 pounds). If this effect should be consistently produced in the laboratory, the addition of vibration to the longitudinal restraint test should be seriously considered.

TABLE 3. RESULTS OF GAUGE WIDENING AND LONGITUDINAL RESTRAINTS TESTS ON 4-TIE PANELS OF WOOD TIES

LONGITUDINAL RESTRAINT TESTS

Data Source: [11]

Fasteners	LONGITUDINAL FORCE AT SLIP (PER RAIL SEAT - POUNDS)
2 German K Fasteners 4 German Screw Spikes	6310
2 Compression Clips 2 Hairpin Spikes	4845
2 Compression Clips 2 Cut Spikes	4595
2 Compression Clips 3 Cut Spikes - Anchor Holes	4375
1 German K Fastener 1 O.E. Clip 4 German Screw Spikes	4250
2 DE Clips, 1/8" Pad 4 German Screw Spikes	4000
2 Cut Spikes - Anchor 2 Cut Spikes - Line 2 Fair Rail Anchors in Test Panel	3735
2 Pandrol Springs 3 Hairpin Spikes - Anchor	2875
2 D.E. Clips 4 German Screw Spikes	2845
1 Compression Clip 2 Cut Spikes	2735
Resistance of Tie in Ballast-1000-2000 Lb.	
2 Cut Spikes - Line 3 Cut Spikes - Anchor	342
2 Cut Spikes - Line 2 Cut Spikes - Anchor	110

GAUGE WIDENING TESTS

(4-Tie Test Panel)

Fasteners	TOTAL RAIL-TO-RAIL FORCE TO CAUSE GAGE WIDENING BY ONE INCH (POUNDS)
1 German K Fastener, 1 OE Clip 4 German Screw Spikes	31,500*
2 Compression Clips - Gage Side 3 Cut Spikes in Anchor Holes	29,800
2 Compression Clips 2 Hairpin Spikes	20,500
2 Compression Clips 2 Cut Spikes	17,000
1 Compression Slip 2 Cut Spikes	16,200
2 DE Clips 4 German Screw Spikes	15,800
2 DE Clips - 1/8" Pad 4 German Screw Spikes	15,000
2 Pandrol Clips 3 Hairpin Spikes	14,600
2 Cut Spikes - Line 3 Cut Spikes - Anchor	13,100
2 Cut Spikes - Line 2 Cut Spikes - Anchor	10,400

*Test of this fastener stopped at lateral deflection of .58", caused mainly by tie bending. All other fasteners were tested to 1" deflection.

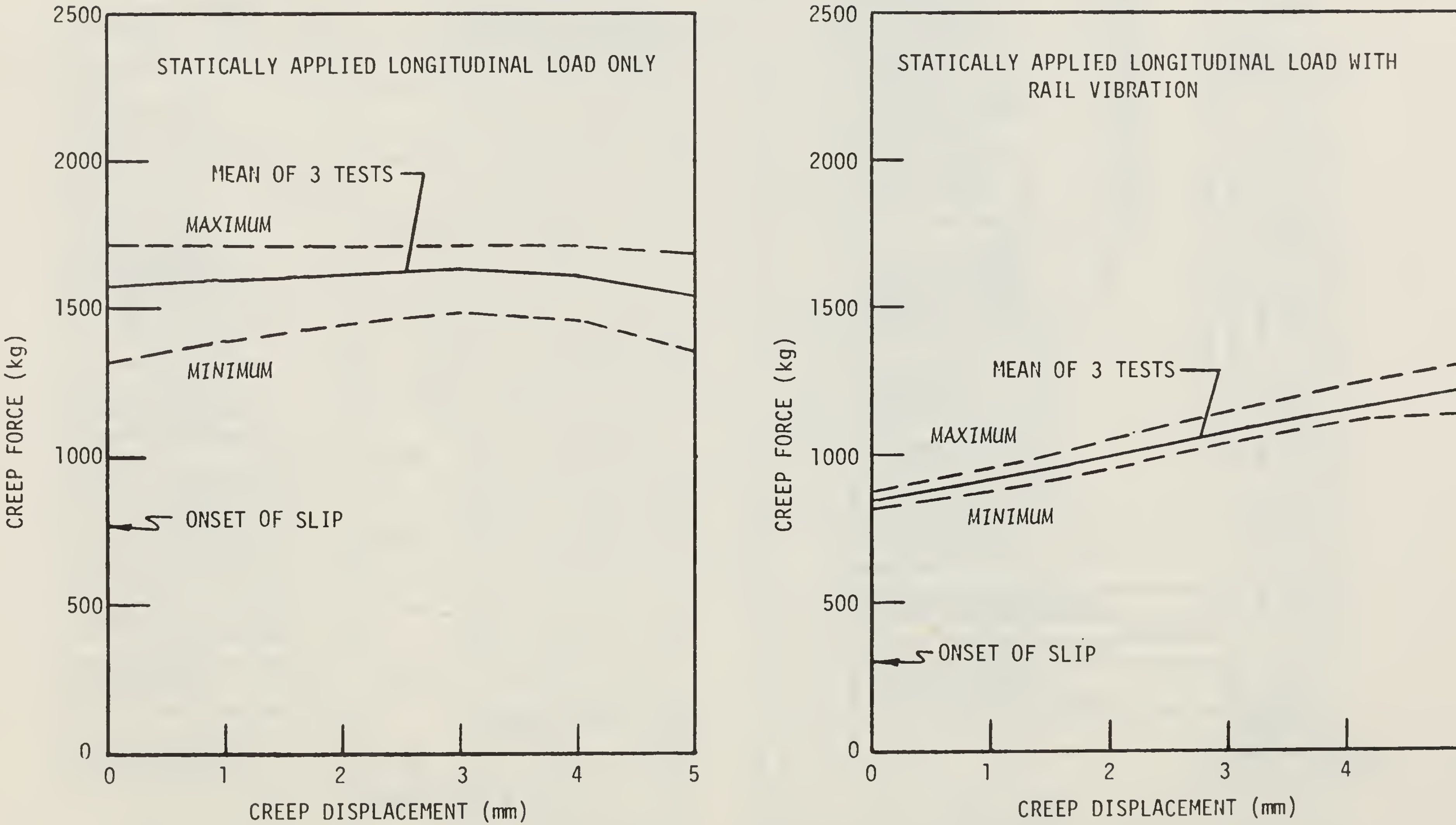


FIGURE 7. COMPARISON OF LONGITUDINAL RESISTANCE WITH AND WITHOUT RAIL VIBRATION (EUROPEAN TESTS OF ELASTIC CLIP FASTENER ON WOOD TIE)

FASTENER PERFORMANCE EXPERIMENTS

In an effort to develop fastener qualification requirements which would provide correlation between observed laboratory and service performance, Battelle conducted an experimental program in three phases:

a. Rail/tie deflections and fastener clip strains were measured at FAST to define representative, severe fastener loading environments. This effort is described in Reference 1.

b. Static measurements of fastener load-deflection characteristics were conducted in the laboratory to:

   (1) determine the load combinations required to reproduce the maximum strains and deflections measured at FAST

   (2) compare the track-measured strains and deflections with those produced during conduct of current qualification tests

   (3) examine the current methods of determining basic clip and pad characteristics.

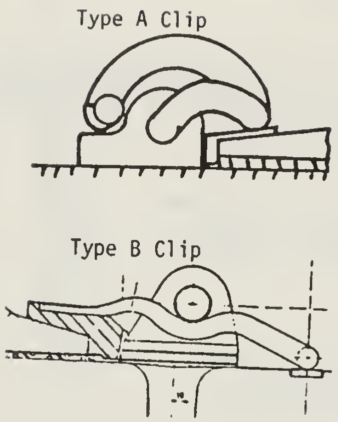
c. Fatigue tests were conducted on one concrete tie fastener system and one wood tie fastener system, both of which are among the types used at FAST. This was done to compare the results of the tests with performance observed in service.

The following sections discuss the results of these experiments as they relate to the development of fastener performance requirements.

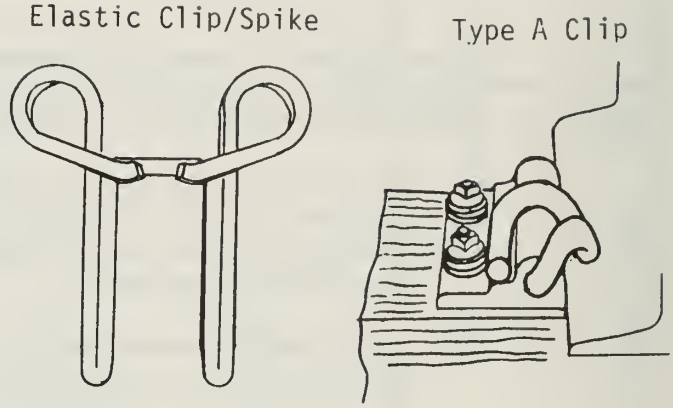
Track Measurements at FAST

To define severe fastener loading environments which could be simulated in the laboratory, rail/tie deflections and fastener clip strains were measured on 5-degree curves of concrete and wood tie track at FAST. Two concrete tie fasteners and two wood tie fasteners were examined, Figures 8(a) and 8(b). Measurements were made at three sites in each fastener subsection. Each fastener used an elastic clip to constrain the rail.

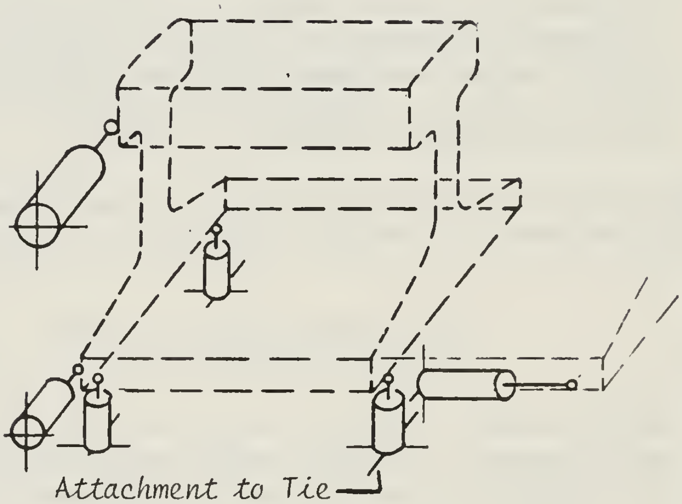
Deflection measurements, Figure 8(c), consisted of three vertical rail/tie deflections at the rail base, one lateral at the rail base, one lateral at the rail head, and one longitudinal. In one subsection of each type of track where a common clip (Type A) was installed, fastener clip strains were also measured. The instrumentation of clips to measure strain is described in Appendix B.



(a) Concrete Tie Fasteners



(b) Wood Tie Fasteners



(c) Rail/Tie Deflection Measurements

FIGURE 8. FIELD MEASUREMENTS AT FAST: FASTENER TYPES AND DISPLACEMENT COMPONENTS

Train loads were produced by a consist of two locomotives and twenty loaded 100-ton hopper cars. Train runs were made in both clockwise and counterclockwise directions for measurements in the concrete tie section, where a 2-percent grade contributed to greater deflections for counterclockwise (upgrade) travel. Only clockwise runs were made over the wood tie section where the grade and its effect were much lower.

The major results of the track measurements were:

a. Peak lateral deflections between the rail head and tie approached 0.100 inches on both types of track.

b. Vertical rail/tie deflections of rail clips in the concrete tie section approached 0.040 inches in both gauge side uplift and field side compression.

c. Measurements in the concrete tie section were made in a subsection containing a very rigid polyethylene pad (7.5 million lb/in spring rate) and in a subsection containing a relatively flexible pad (1.3 million lb/in spring rate). Peak deflections were about 30 percent higher for the hard pad than for the soft pad.

d. Vertical rail/tie deflections in the wood tie section reached 0.100 inches in field side compression. However, where the fastener clip was attached to the tie plate (Type A clip), most of the vertical deflection took place through tie plate bending rather than through clip deflection.

The peak vertical rail/tie deflections at the fastener clips were calculated from the three vertical deflection measurements illustrated in Figure 8(c). The data points in Figure 9 summarize the peak vertical deflections and the simultaneously occurring peak clip strains for the Type A clip. The next section compares the measured data with the strain-deflection relationships measured in the laboratory and also shown in Figure 9.

Clip Force-Deflection-Strain Characteristics

Comparison With Track Measurements

Track measurements of clip strain vs. clip deflection were compared with similar data produced by two laboratory methods:

Method 1 - by vertical loading of an individual clip, as described in Appendix C

Method 2 - by loading through a rail segment to simulate the lateral and vertical components experienced in track. The lateral restraint fixture used for this purpose is shown later in Figure 19.

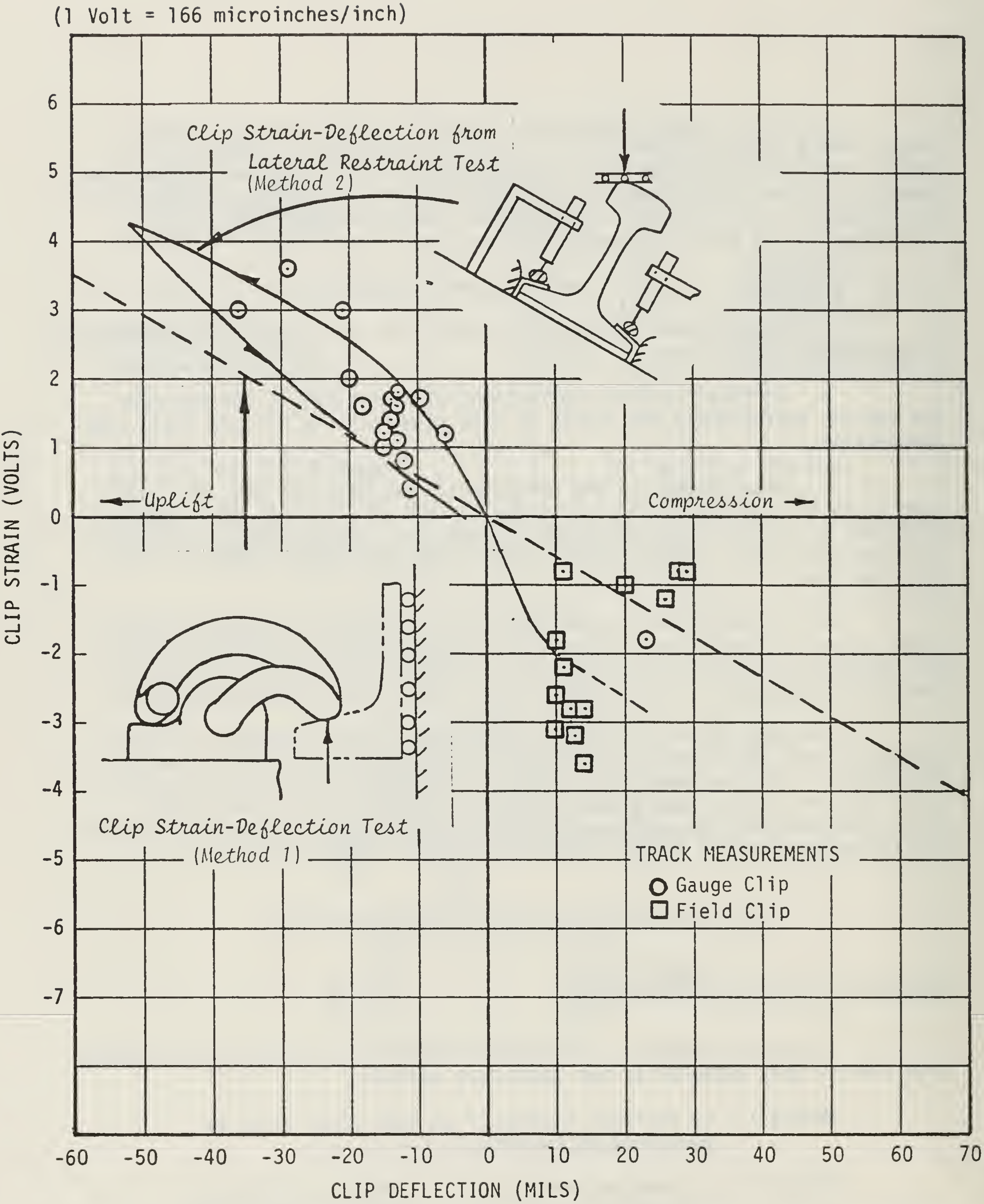


FIGURE 9. VERTICAL CLIP DEFLECTION VS. CLIP STRAIN FROM TRACK MEASUREMENTS AND TWO LABORATORY TESTS

Figure 9 shows schematics of the two loading arrangements and the three strain-deflection relationships. The results show that:

a. The peak clip strain level was found in the track at vertical deflections between 0.030 inches and 0.037 inches of vertical rail/tie deflection

b. The reproduction of this peak clip strain required over 0.060 inches of vertical clip deflection by Method 1 but only 0.038 inches by Method 2. The clip strain-deflection relationship obtained from Method 2 correlates with the field results much better than does that of Method 1. It can be concluded that the clip receives substantial strain from lateral loading as well as from vertical loading when installed in track. Thus, the vertical rail/tie deflection of the clip will not provide a good indicator of the level of clip strain.

The data in Figure 9 can be used to explain an apparent anomaly between the field measurements of rail/tie deflection and the results of fatigue tests conducted by the clip manufacturer [13]. It is known that substantial numbers of these clips have fractured in service on the 5-degree curve of the concrete tie section at FAST. Therefore, the clip strains experienced in track must exceed the fatigue limit of the clip.

The manufacturer subjected the clip to fatigue tests with a loading arrangement equivalent to that of Method 1. Tests were conducted by imposing cyclic vertical deflections (measured relative to the nominal installed clip position) at levels of 0.020 to 0.060 inches in 0.010-inch increments. With a 2000-pound toe load and cyclic deflection of 0.050 inches, the clips did not fail in tests up to 15 million cycles. With the same toe load and cyclic deflection of 0.060 inches, the clips failed in less than one million cycles. An increase in toe load to 2400 pounds caused failures within one million cycles at 0.040 inches of cyclic deflection.

Clip toe loads measured by the manufacturer at FAST did not exceed 1580 pounds [14]. The vertical rail/tie deflections measured under this program did not exceed 0.037 inches. However, the fatigue limit of many of the clips in track was exceeded. The apparent anomaly between service performance and the manufacturer's fatigue tests can be explained by observing the differences in strain levels produced by the previously described laboratory Methods 1 and 2. It is evident that the clip strain levels imposed by combined vertical and lateral loads, either in track or simulated in the laboratory (Method 2) do exceed the fatigue limit of some of the Type A clips. This limit is reached at 3.0-3.5 volts clip strain on the scale of Figure 9, or 0.050-0.060 inches deflection by Method 1.

Method of Determining Clip Yield Load

A simple and repeatable method for determining the vertical yield load of an individual clip was suggested by a manufacturer* and duplicated

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*Portec, Inc.

at Battelle. The method requires a fixture for the vertical loading of an individual clip, such as the arrangement described in Appendix C, and a vernier caliper or dial gauge capable of displacement measurements to 0.001 inches. The following procedure is used:

a. Place the clip on a flat surface and measure the height of the clip toe or other characteristic dimension.

b. Select a value of vertical force which is known to be less than the yield load. Apply the vertical load to this point and release it. Typical load-deflection curves are shown in Figure 10.

c. Repeat step a.

d. Repeat step b with the load increased by 100-200 pounds.

This process is continued until the characteristic dimension begins to change and several post-yield points are collected. Straight-line curve fits of pre-yield and post-yield data will intersect at the yield load. Typical data for 2 types of clips are illustrated in Figure 11.

The clip yield load should be compared with the nominal toe load of the clip. A sufficient margin between toe load and yield load should be maintained to assure that yield will not occur under the worst combinations of displacements produced by train loads and construction/assembly tolerances.

Tie Pad Compression Tests

The fixture shown in Figure 12 has been used to perform both static and dynamic compression load tests on a wide variety of pads which differ in material, thickness and shape factor (grooving or molding to reduce stiffness). Examples of pad stiffness are shown in Figure 13 through 15. Some general trends from the tests were:

a. Compressive stiffness is highly dependent on the rate of loading for some pads but almost independent of loading rate for others. Extremes are shown in Figure 14 (dependent) and Figure 15 (independent). In general, the hard pad materials (polyethylene, polyurethane, EVA) have stiffnesses which are relatively independent of loading rate. Neoprene is relatively independent except where severe shaping causes a sharp change in stiffness as the pad is compressed. A loading rate of 10 cycles per second is recommended.

b. Load-deflection curves should never be recorded until at least several complete load cycles have been applied, even when the load application is quasistatic. Load cycles should vary from low load to the maximum desired, rather than from zero load to maximum load. Substantial differences will occur in any definition of the "zero" load-deflection point.

c. Shaping of pads to achieve flexibility (lower stiffness) can be detrimental to the objective of tie impact load attenuation if the shaping

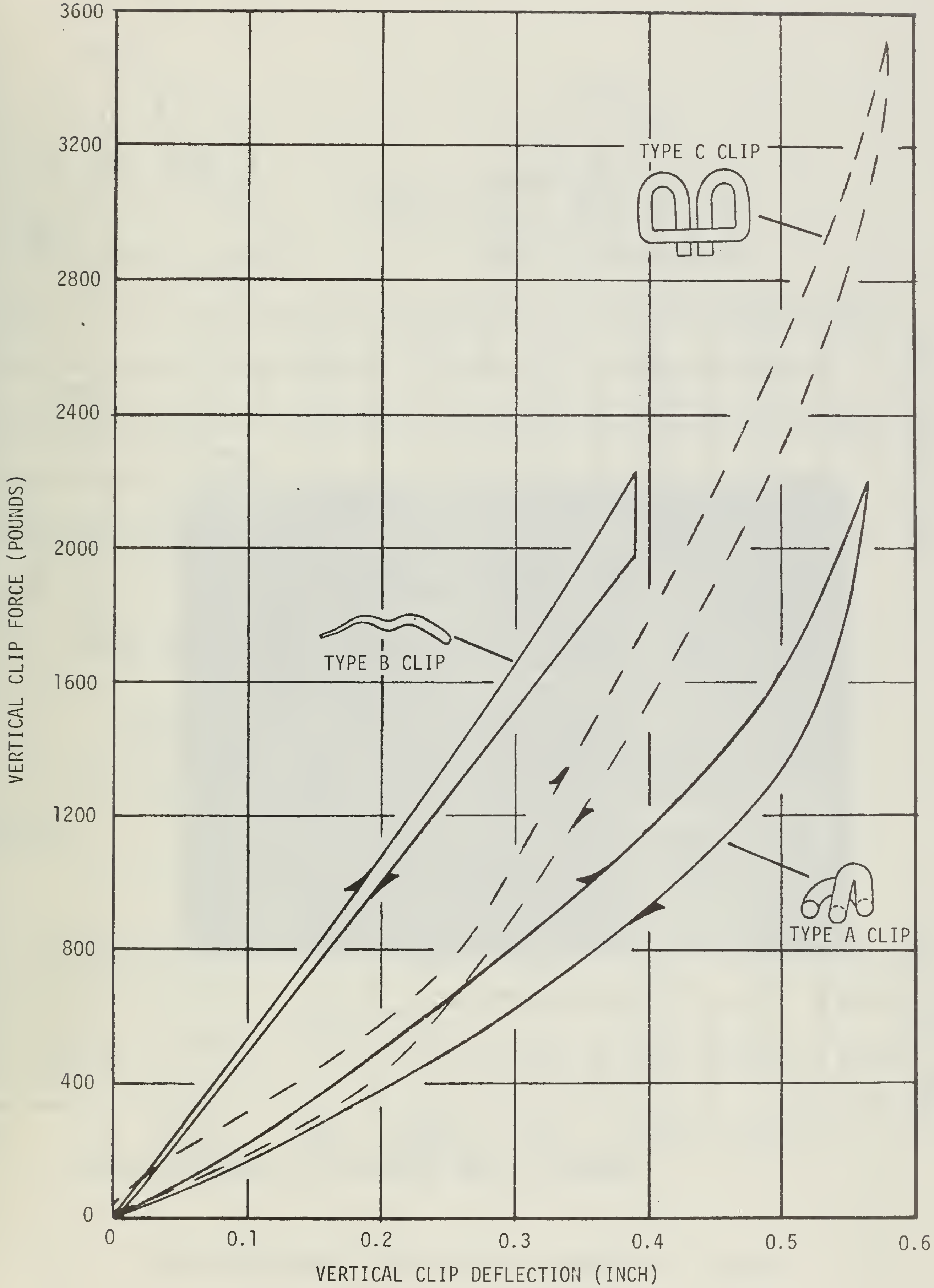


FIGURE 10. TYPICAL CLIP FORCE-DEFLECTION CHARACTERISTICS

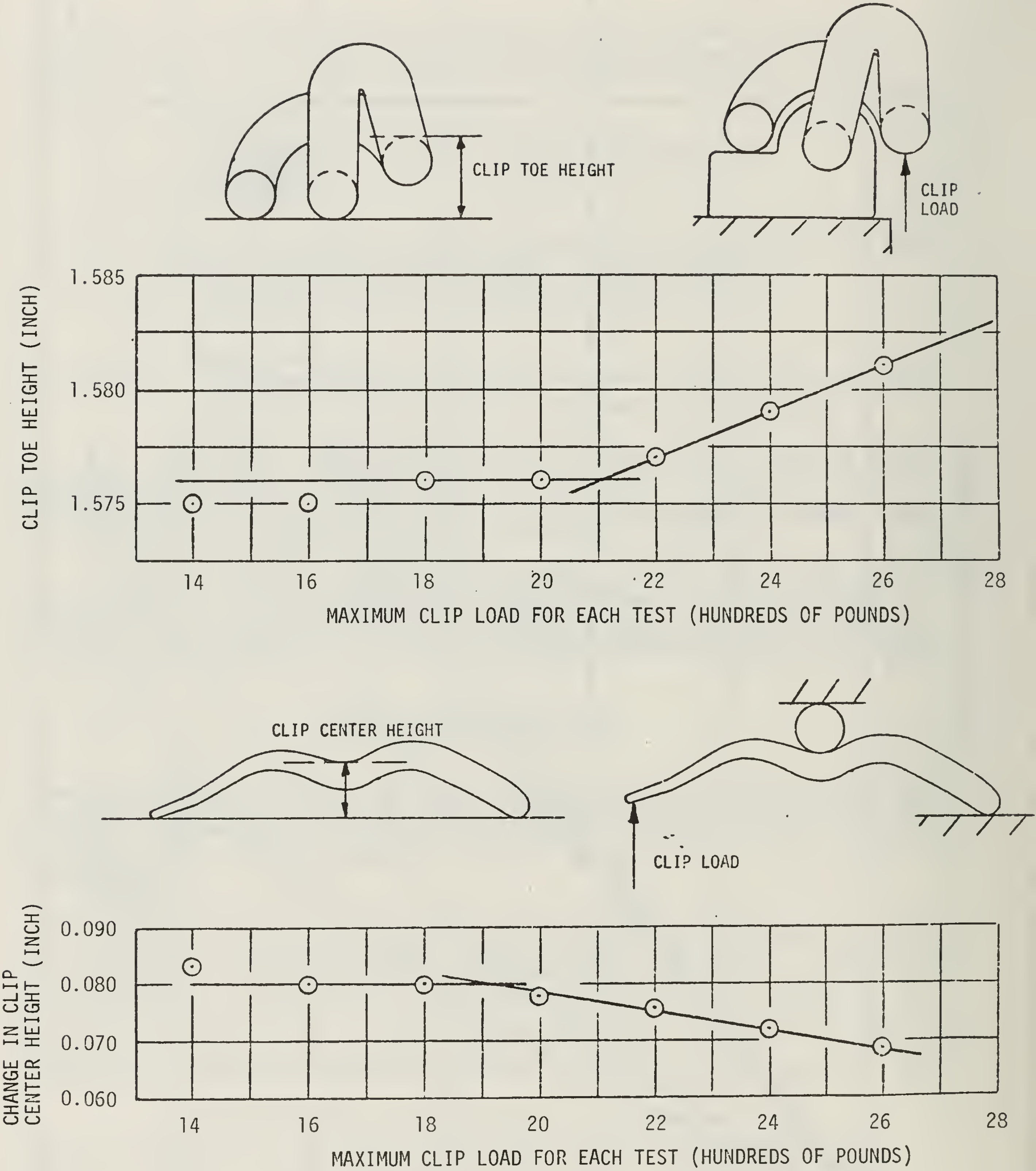


FIGURE 11. DETERMINATION OF CLIP YIELD POINT FOR TWO CLIPS

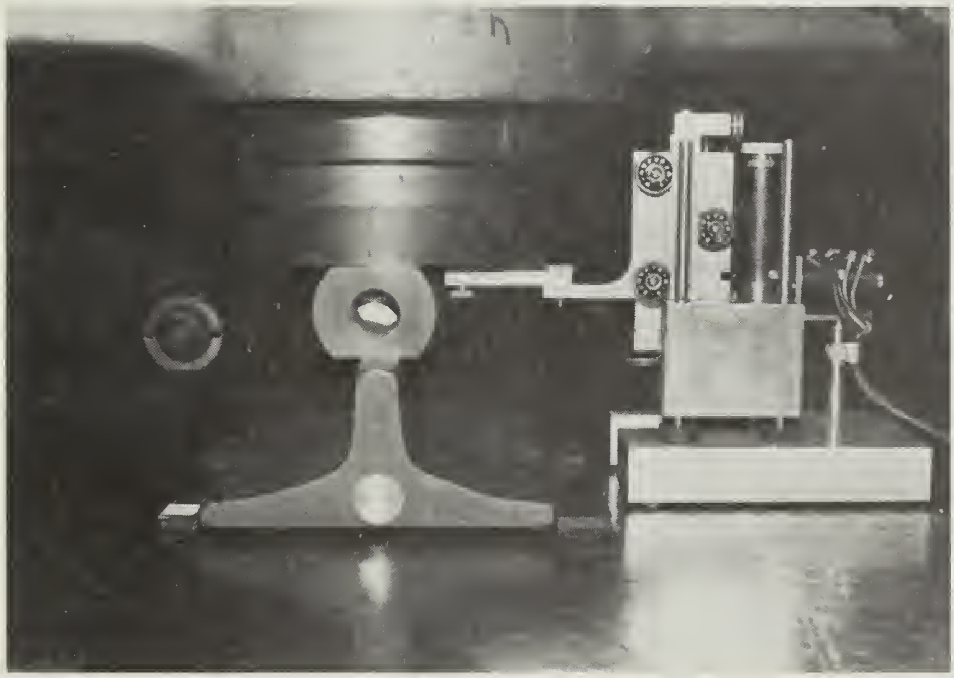


FIGURE 12. LOADING ARRANGEMENT FOR TIE PAD COMPRESSION TESTS

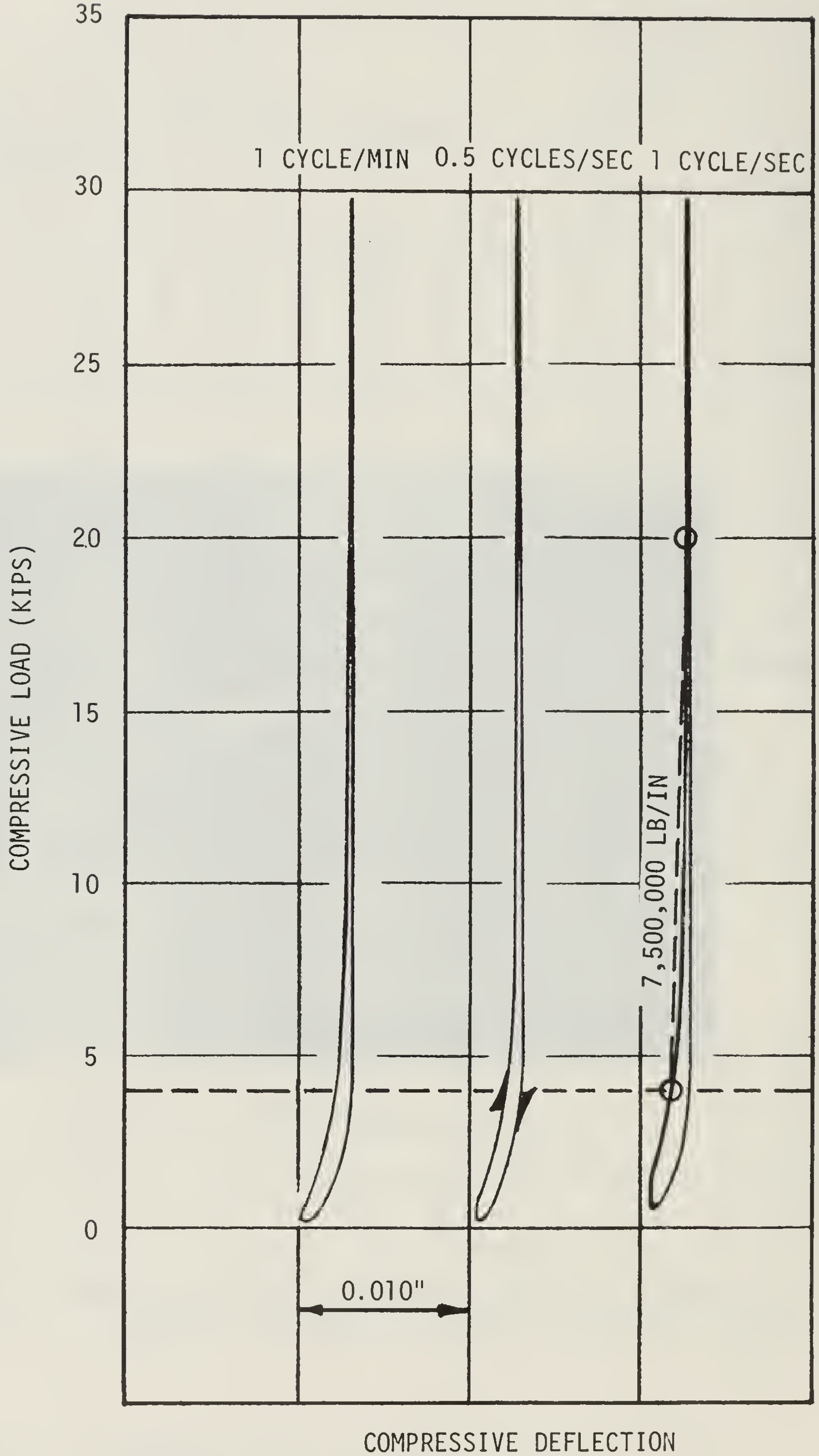


FIGURE 13. VERTICAL LOAD-DEFLECTION CHARACTERISTICS FOR THE POLYETHYLENE PAD

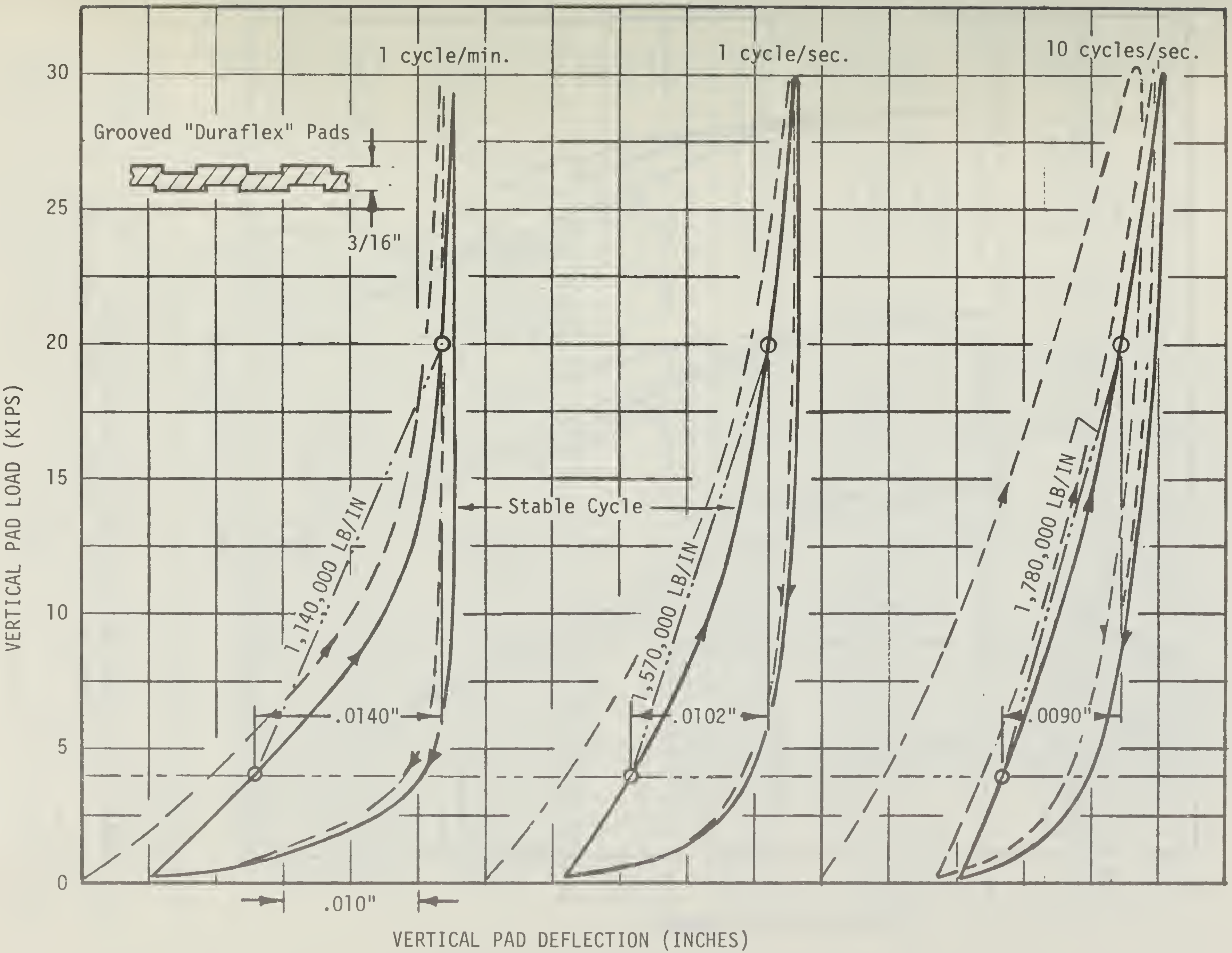


FIGURE 14. EFFECT OF CYCLE RATE ON LOAD-DEFLECTION CHARACTERISTIC OF GROOVED "DURAFLEX" PADS

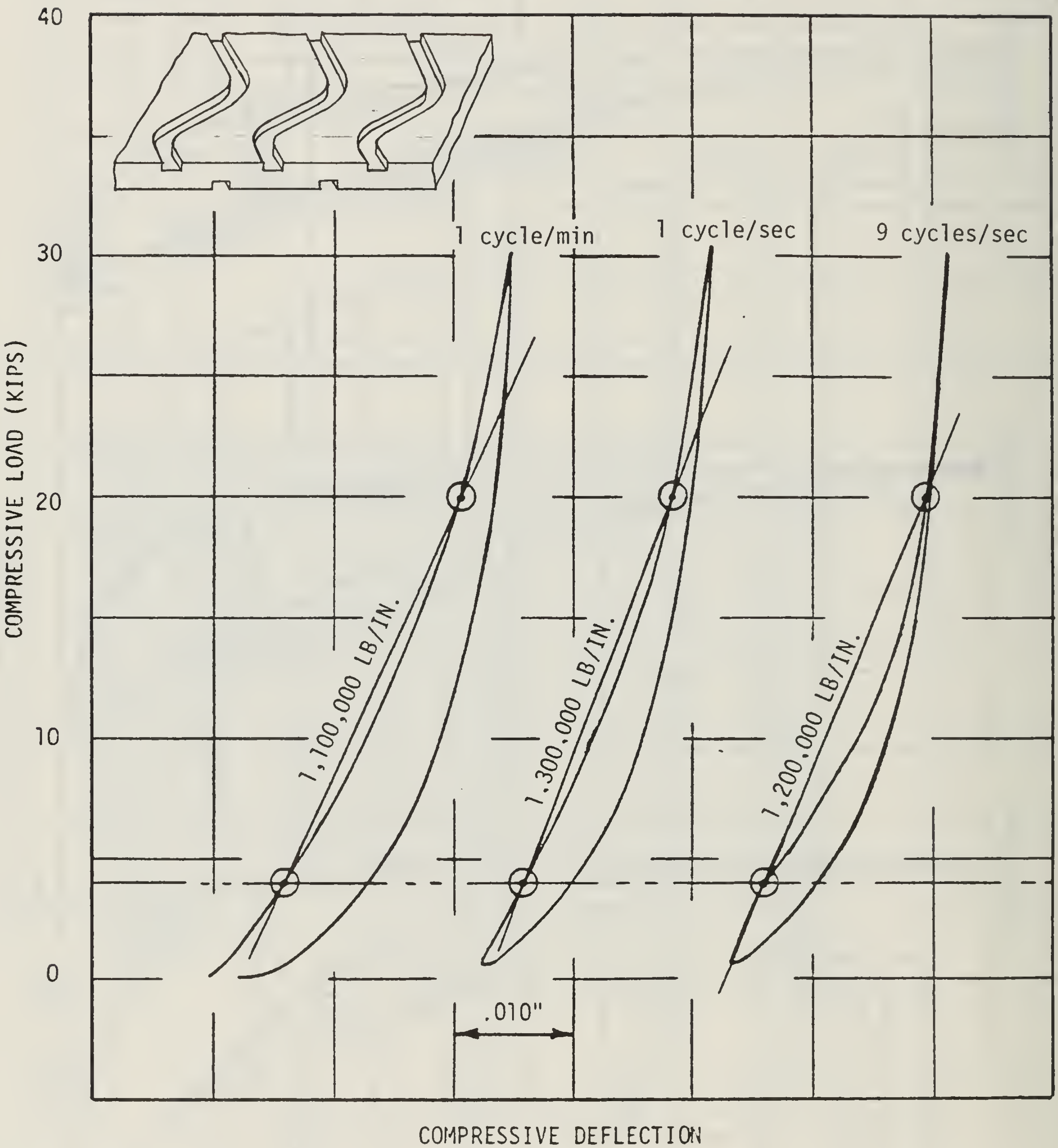


FIGURE 15. EFFECT OF CYCLE RATE ON LOAD-DEFLECTION CHARACTERISTICS OF GROOVED SYNTHETIC RUBBER PAD

does not allow for the gradual transition of stiffness with increase in compression. The pad shown in Figure 14 is made of moderate durometer material and is grooved to achieve a radical shape factor. However, the pad grooves "bottom" at less than 15,000 pounds. The effectiveness of this pad in attenuating large impact loads is quite low in comparison to other pads with approximately the same average stiffness [9]. This experimental pad shape has been abandoned by the manufacturer.

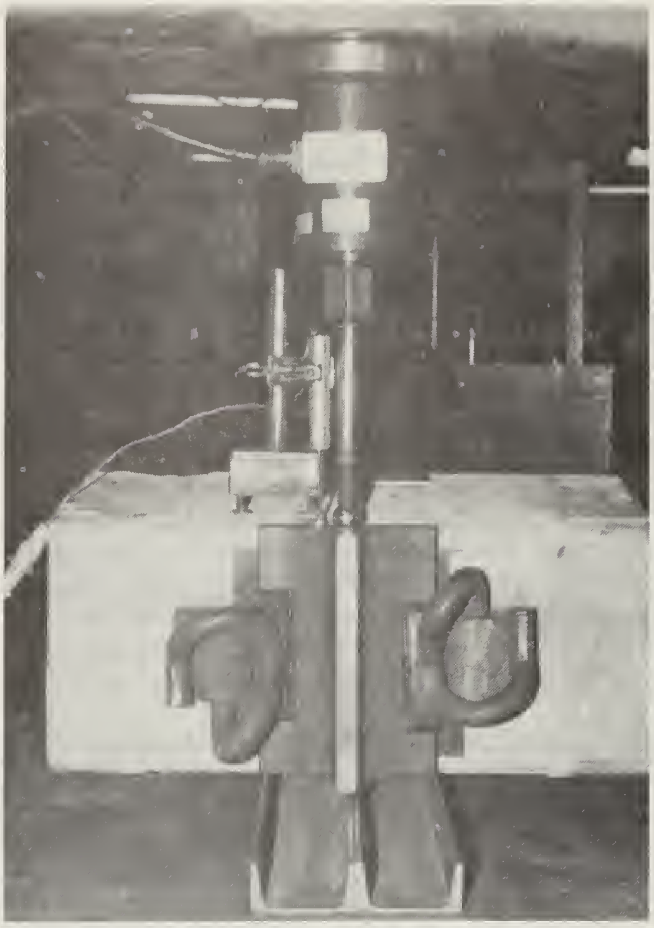
Longitudinal Restraint Tests

Longitudinal restraint tests were conducted to determine whether a dependence could be found between longitudinal restraint and either (1) tie pad stiffness, or (2) the presence or lack of external insulators. It was quickly discovered that the dependence of longitudinal restraint on any single test factor was very difficult to isolate. Problems encountered in the development of an acceptable test procedure are discussed as follows.

Early trials with the fixture of Figure 16(a) revealed that the fastener clips could not be depended upon to provide consistent toe loads. Successive tests with the same pad resulted in losses of longitudinal slip load by up to 15 percent. The installation and removal of clips caused clip deformation and wear of the fastener shoulders and insulators. Where insulators were not used, the clip toe and rail base became polished. Therefore, it was necessary to devise a method of applying controlled vertical loads to the clip toe areas of the rail base. This was done with the fixture shown in Figure 16(b). Controlled vertical loads were applied by a mechanical test machine to a fixture with two bearing surfaces which simulated toe loads. The vertical load was applied through rollers to prevent reaction of longitudinal load by the vertical load fixture. Also, the vertical fixture was constrained against longitudinal displacement by reaction of the fixture against the fastener shoulders. Longitudinal load was applied and measured by placing a hand-pumped hydraulic cylinder in line with the load cell.

After vertical load control was established, it was found that test repetitions with the same pad and insulator would not consistently provide the same results. A sequence of tests yielded a general downward drift of longitudinal restraint under identical test inputs. To maintain comparable values of slip load, it was necessary to change the test specimens (pads and insulators) after each measurement. This process was continued until three values of slip load were obtained for each combination of pad, insulator and vertical applied load. The mean of slip loads obtained with identical test inputs was used to form comparisons.

Figure 17 presents the results of tests conducted on two pads which represent extremes in pad stiffness and coefficient of friction among those tested. The two pads also produced extremes in longitudinal slip load as a function of vertical applied load. Tests were run with and without insulators of the metal-plastic shim type. The tests with insulators yielded higher loads for both pads, but the difference with and without insulators was much greater for the rigid pad than for the flexible pad. It is possible that the difference in longitudinal stiffness of the two pads causes the insulators to interact differently.



(a) Toe Load Provided by Clips

(b) Toe Load Provided by Test Machine

FIGURE 16. LOADING FIXTURES USED FOR LONGITUDINAL RESTRAINT TESTS

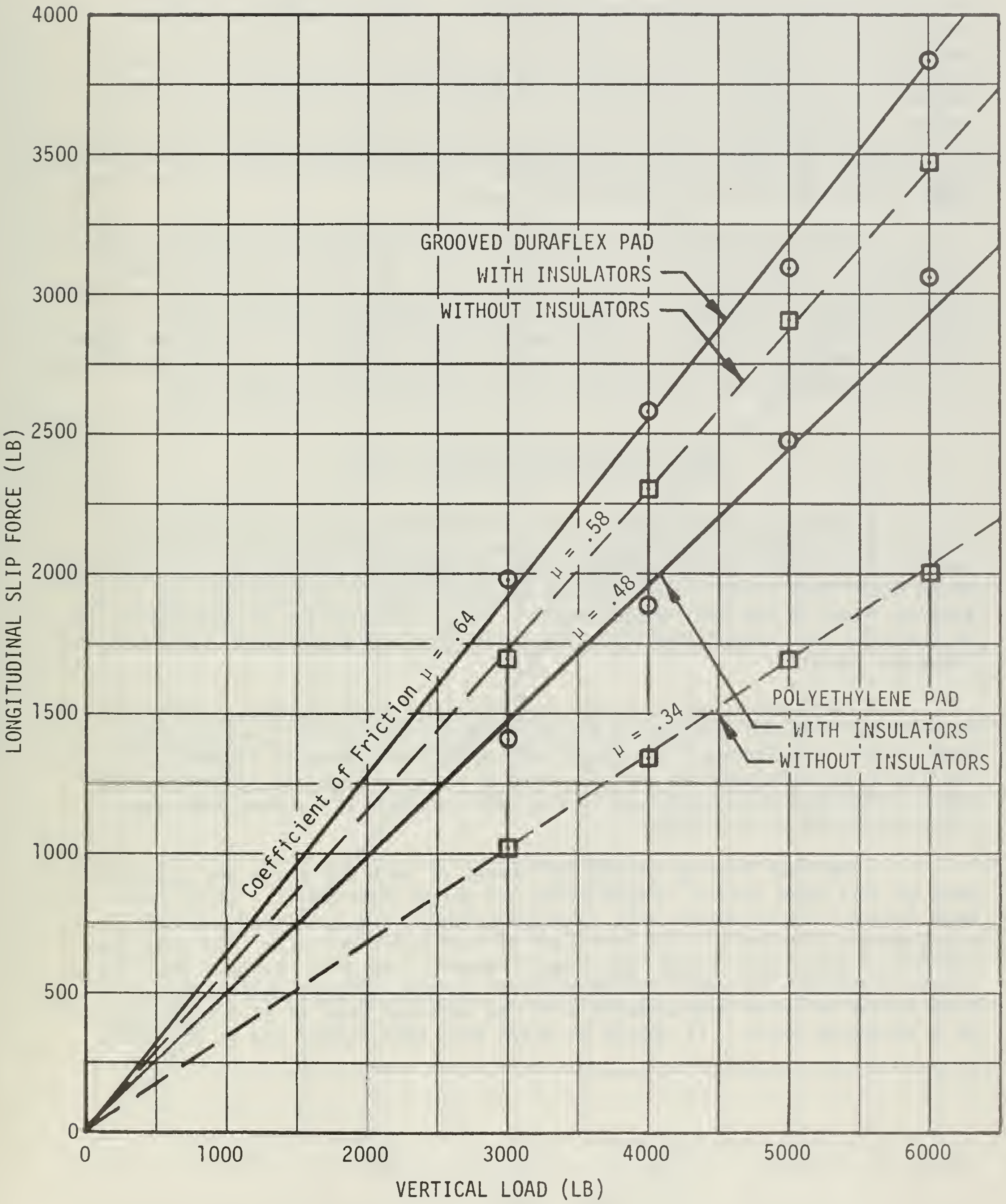


FIGURE 17. INFLUENCE OF PADS AND INSULATORS ON LONGITUDINAL RESTRAINT OF CONCRETE TIE FASTENERS

While the two pads vary widely in stiffness, they also differ in the shape and texture of the bearing surfaces. The polyethylene pad has solid and very smooth bearing surfaces. The Duraflex pad is made of a soft polymer with a comparatively rough surface texture and is grooved to lower stiffness. Typically, the Duraflex pad would permit about twice the longitudinal rail-tie deflection before the onset of slip (0.010 inches vs. 0.005 inches for 4000-pound vertical load). This longitudinal flexibility could be a significant factor in the creep resistance of installed ties. The FAST measurements described earlier showed that longitudinal rail/tie deflections under train loads did not exceed 0.010 inches.

Similar longitudinal restraint results are shown in Figure 18 for the wood tie fastener which uses a Type A clip. The restraint at a given vertical load falls between those of the concrete tie fasteners shown in the previous figure. However, it should be noted that the onset of slip is almost instantaneous for this case where the rail contacts a steel tie plate. Most measured deflections before slip fell below 0.0002 inches. The system has no flexibility to permit longitudinal rail/tie deflection without slip.

Lateral/Rollover Restraint Tests

Lateral/rollover tests were conducted with a range of L/V angles from 20 to 30 degrees and with pads of varying stiffness. The primary purpose of this effort was to determine the combinations of load and L/V angle which could most closely simulate the maximum rail/tie deflections and clip strains found in the FAST measurements. This also provided an opportunity to evaluate the current qualification tests for lateral/rollover restraint and repeated loads.

The fixture used to vary the L/V angle, apply vertical loads, and measure rail/tie deflections is illustrated in Figure 19. Curves for rail head lateral displacement and gauge clip uplift are shown in Figure 20 for the rigid polyethylene pad and in Figure 21 for the flexible synthetic rubber pad. These pads were installed in the FAST concrete tie subsections where field measurements were made.

The data display strong influences of both L/V angle and pad stiffness on rail head lateral displacement and gauge clip uplift. Since rail base lateral displacements were relatively small, the rail head lateral displacement provides a good indicator of rail rollover. The load range was limited to avoid destroying the clips. However, the data indicate that the flexible pad may not have limited the rail to the rollover restriction of 0.25 inches rollover displacement with the vertical load of 20.5 kips applied at a 30-degree angle. It should be noted that this rubber pad is not among

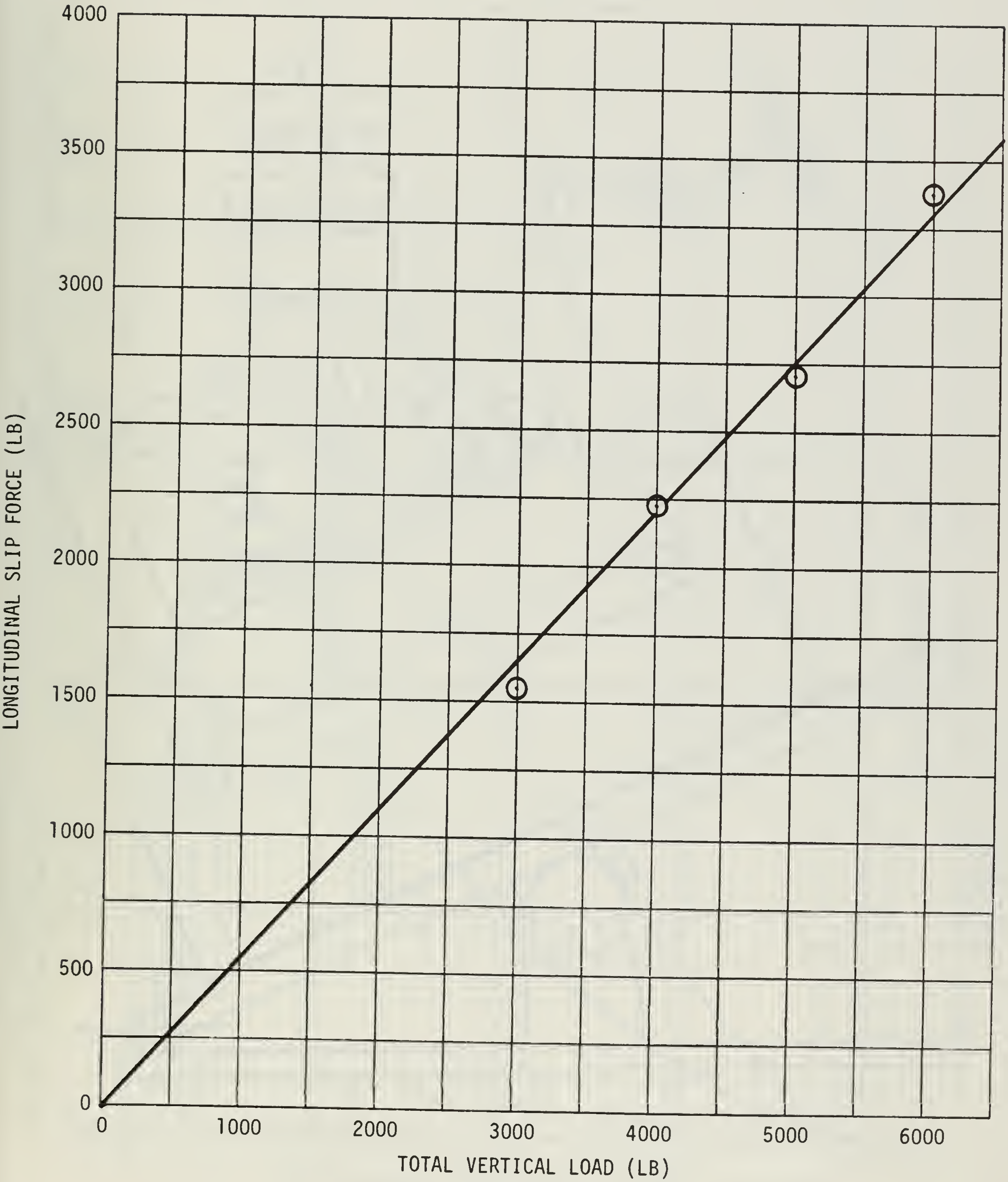


FIGURE 18. LONGITUDINAL RESTRAINT OF WOOD TIE FASTENER SYSTEM

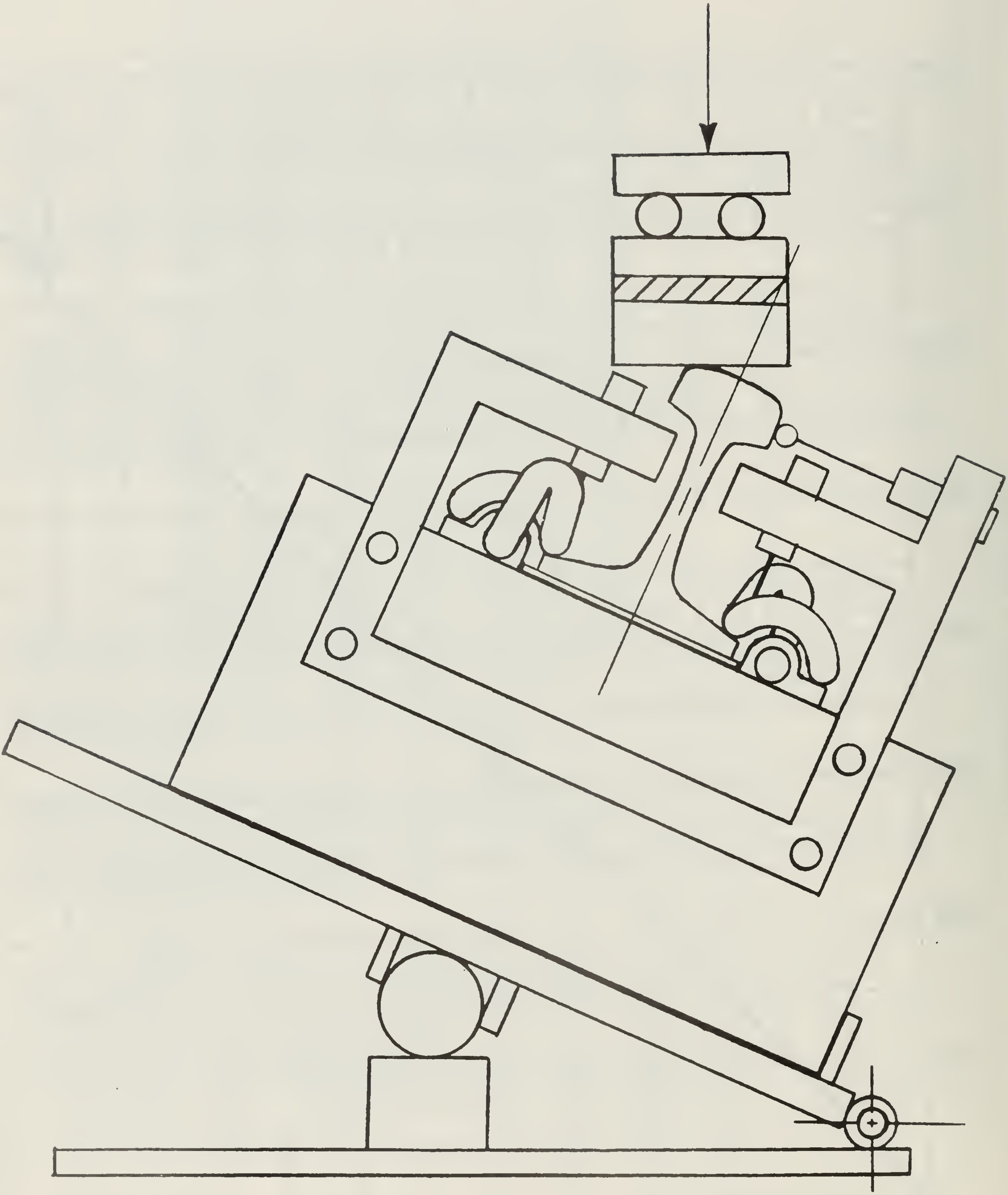


FIGURE 19. LOADING AND MEASUREMENT SCHEMATIC FOR LATERAL/ROLLOVER RESTRAINT TESTS

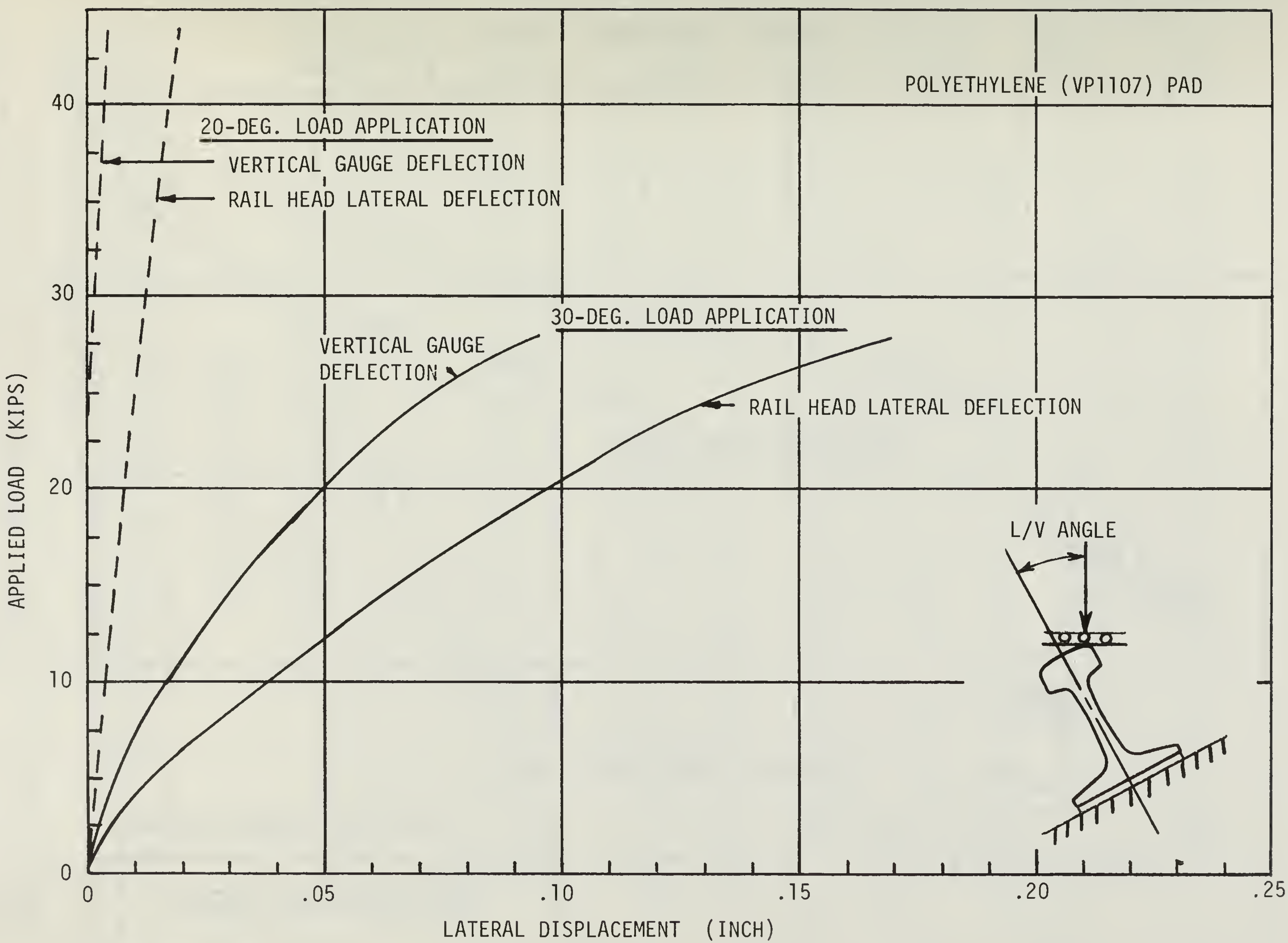


FIGURE 20. APPLIED LOAD VS. DISPLACEMENT FOR LATERAL RESTRAINT TESTS AT 20 AND 30 DEGREES, HARD POLYETHYLENE PAD

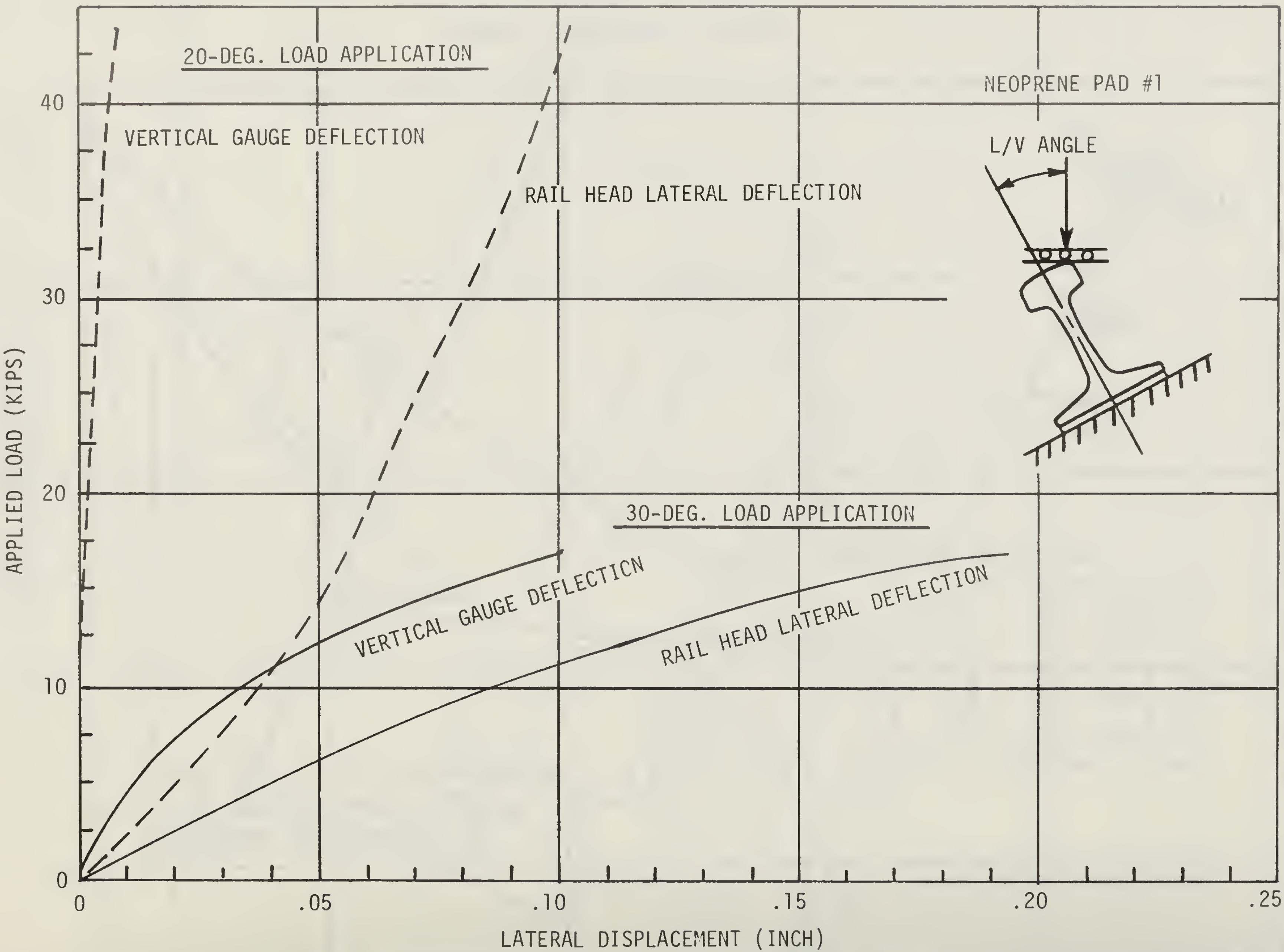


FIGURE 21. APPLIED LOAD VS. DISPLACEMENT FOR LATERAL RESTRAINT TESTS AT 20 AND 30 DEGREES, GROOVED SYNTHETIC RUBBER PAD

the most flexible pads in use on mainline railroads in Europe and Japan. For adequate attenuation of impact strain under high speed traffic, it may be necessary to use a much softer pad [9]. The results show a need for the evaluation of the gauge widening and rollover allowed by very flexible pads on curved track under 100-ton traffic. This would provide the information required for selection of rollover restraint criteria which assured track safety without representing an unnecessary restriction on the use of flexible pads.

The most important information in Figures 20 and 21 concerns the specifications for repeated loads tests (Test 4 of Table 1). The AREA repeated load test is conducted at an L/V angle of 20 degrees, while the effective L/V angle for the Amtrak test is 18 degrees. From Figure 20 it can be seen that a test conducted at the 20-degree L/V angle to a maximum load of 30 kips produced about 0.015 inches of rail head lateral deflection. The results in Figure 21 for the flexible pad produced very little vertical rail/tie deflection, although substantial rail head lateral deflection occurred (80 mils at 30 kips). Most of this deflection resulted from lateral translation of the rail segment.

The vertical displacement is partially compensated in the AREA tests by the uplift load of 0.6 x pad separation load. However, the strain-deflection results presented in the next section show that the uplift load primarily affects field clip uplift deflection while the compressive load primarily affects gauge clip uplift deflection. Uplift loads were required for the fatigue tests to produce a balance of the peak-to-peak vertical rail-to-tie deflections on the field and gauge sides.

The lateral restraint tests indicate that the repeated loads currently conducted at a 20-degree loading angle do not provide rail/tie displacements representative of a severe loading environment for rigid pads. The tests also indicate that rail/tie displacements are highly sensitive to L/V angle and pad stiffness. Given these sensitivities, it is reasonable to assume that the tests can be affected by the details of test fixtures which apply the same nominal loads. For example, a variation of the height of the loading rod attachment to the rail segment or the presence of pivot friction would change the load-deflection relationship. These problems led to the approach, described in the following section, by which the fatigue environment is directly monitored through rail/tie deflections.

Fastener Fatigue Tests

One of the major objectives of this program was to define fastener qualification tests which could simulate the service environments of fasteners. To define the service environments in a way which could be reproduced in the laboratory, rail/tie deflection measurements were made on four fastener systems installed at FAST.

Two of the fastener systems, one on concrete ties and one on wood ties, had required substantial replacements of components. Each system used

the Type A clip. The concrete tie system had experienced clip fallouts and fractures. In addition, where flexible pads of grooved synthetic rubber or corded rubber were installed on the concrete tie track, some abrasive wear and delamination of the pads occurred. On the wood tie system, a few of the tie plates and many of the screw spikes used with the Type A system had fractured. The cause of all component fractures was fatigue loading.

The following subsections describe fatigue tests conducted on one concrete tie fastener system and one wood tie system, both of which use the Type A clip. Loads and L/V angles were adjusted so that the loading arrangement (using an available fixture) reproduced the range of two important rail/tie deflections measured at FAST. In each case, the tests resulted in fatigue failures identical to some of those which have occurred at FAST.

Concrete Tie Fastener Fatigue Test

Figure 22 shows a schematic of the loading and deflection measurement arrangement used for the concrete tie fastener test. Details of the loading fixture are provided in Appendix A. A trial and error search was conducted to determine the combination of L/V angle and load range which would most closely duplicate the rail head lateral deflection and vertical clip deflections measured at FAST.

No attempt was made to conform to the loading geometry of the AREA test which is conducted in an approximately similar manner. It should be pointed out that in no case are the loads applied to a single fastener using a short rail segment equivalent to the wheel/rail loads experienced in track. Through bending and torsional resistance, the rail in track acts to distribute loads to several adjacent ties and fasteners.

The objective of the loading arrangement was to simulate, as closely as possible, the following combination of rail/tie deflections for both rigid and flexible pads:

a. Gauge and field clip vertical deflection: 0.040 inches peak-to-peak
b. Rail head lateral deflection: 0.100 inches peak-to-peak

After initial trials with L/V angles between 20 and 27 degrees, a final selection of 24 degrees was made. To simulate the deflection goals within approximately 10 percent, the following ranges of loads were required for hard and soft pads:

a. Rigid polyethylene pad: 20 kips compression, 2400 pounds uplift

b. Flexible synthetic rubber* or grooved Duraflex pad: 13 - 16 kips compression, 1600 - 2000 lb uplift.

*This is the flexible pad used in Subsections 17-J2 and -K1 of the FAST 3-degree curve.

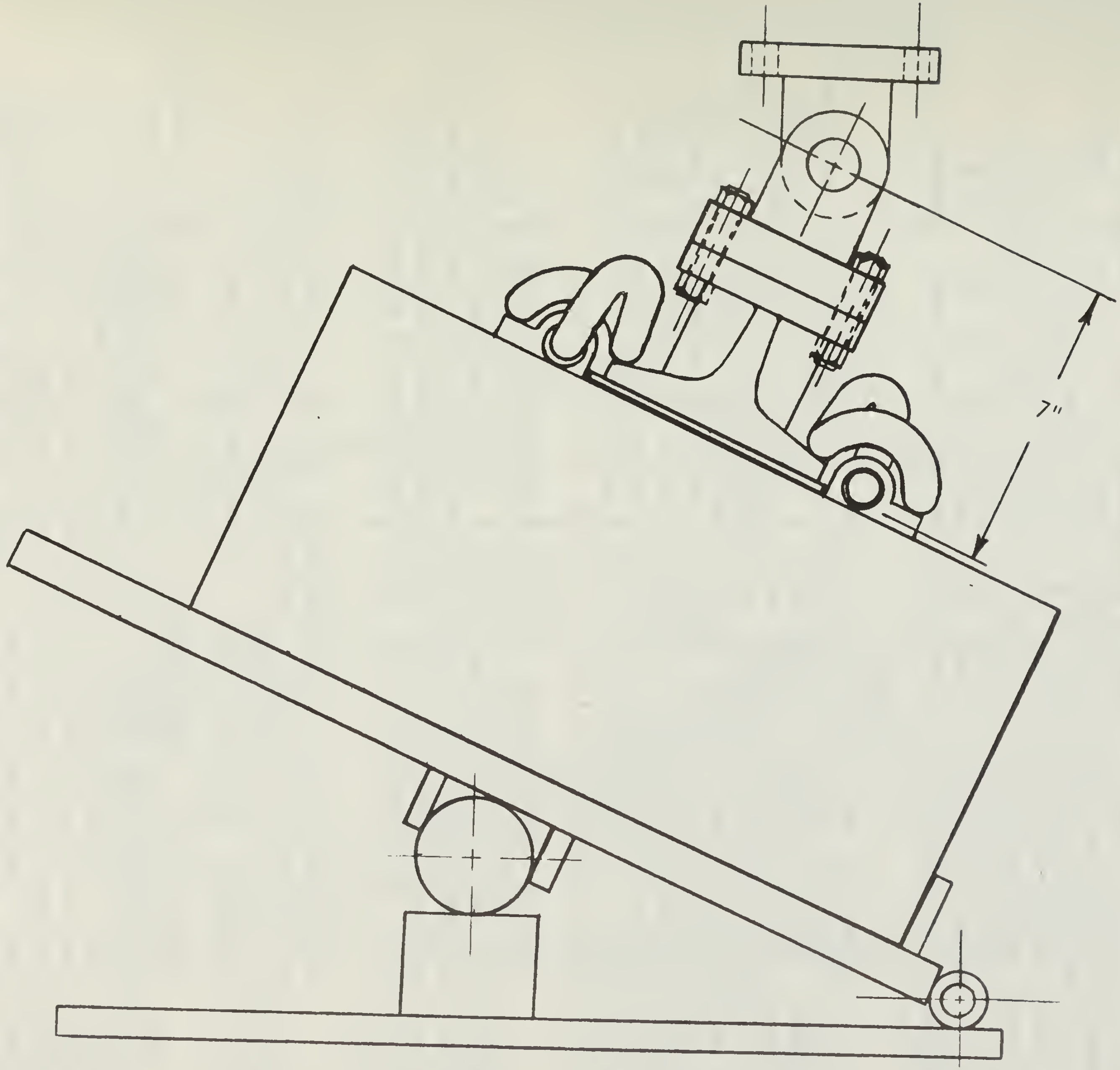


FIGURE 22. LOADING SCHEMATIC FOR CONCRETE TIE FASTENER FATIGUE TEST

During the early stages of fatigue testing, frequent minor adjustments of load levels were required to maintain the desired deflection levels. Two changes to the loading fixture were made during this period:

a. The clevis holes were honed and a pin of hardened 4340 steel was substituted for the original mild steel pin.

b. Grease fittings were added to the clevis.

These measures stabilized the loading arrangement so that the deflections produced by given load levels would remain stable for 8 - 10 hours. Greasing was performed at a maximum interval of 8 hours. A load rate of 2 cycles per second was maintained throughout the initial trials and tests. This rate could have been doubled or halved without significantly affecting the short-term load-deflection relationship. However, a slight heat buildup (about 5 degrees on the rail segment) developed at the 2 Hz rate. This prevented an increase in loading rate, and economics prevented a decrease in the rate.

Three pads were used during the test. The flexible synthetic rubber pad was used through 20,000 cycles when a routine inspection was made. The pad was badly abraded where it contacted the field side edge of the rail base. The hard polyethylene pad was substituted and maintained until 160,000 cycles were completed. No damage occurred. Finally, a flexible grooved Duraflex pad was inserted and retained for the duration of the test (653,000 cycles). The loads were changed as indicated previously to maintain constant rail/tie deflections. An inspection after test completion revealed that this pad had also compressed and abraded where it contacted the field side rail base. An additional circular worn area about 1 inch in diameter was caused by a rough spot of the tie surface.

Figure 23 shows typical load-deflection and strain deflection relationships recorded with the Duraflex pad. These were collected by temporary substitution of instrumented clips during shut-downs for inspections. The desired peak-to-peak clip vertical deflections were very nearly maintained. The rail head lateral deflection was recorded along with the load levels on a strip chart. The lateral peak-to-peak deflection varied between 105 and 115 mils.

At 653,000 cycles it was discovered that the clip had cracked in the location 1 shown on Figure 24. Subsequent microscopic examination revealed that a second crack had formed at location 2. Clips in track had fractured at both of these locations. The test was terminated at this point.

The FAST train, which produced 33 x 10^{-6} MGT per axle, would develop 21.5 MGT by the passage of 653,000 axles. The first group of clip failures in track began about 40 MGT after installation. After the track rebuild at 425 MGT, clips from two different batches began to fail immediately. The test clip came from one of the latter batches. The test represented a severe loading environment since the deflection levels applied in the lab occurred for only a small percentage of axles in track. Considering possible variations in clip properties and loading conditions, the degree of representation of track performance can be judged acceptable.

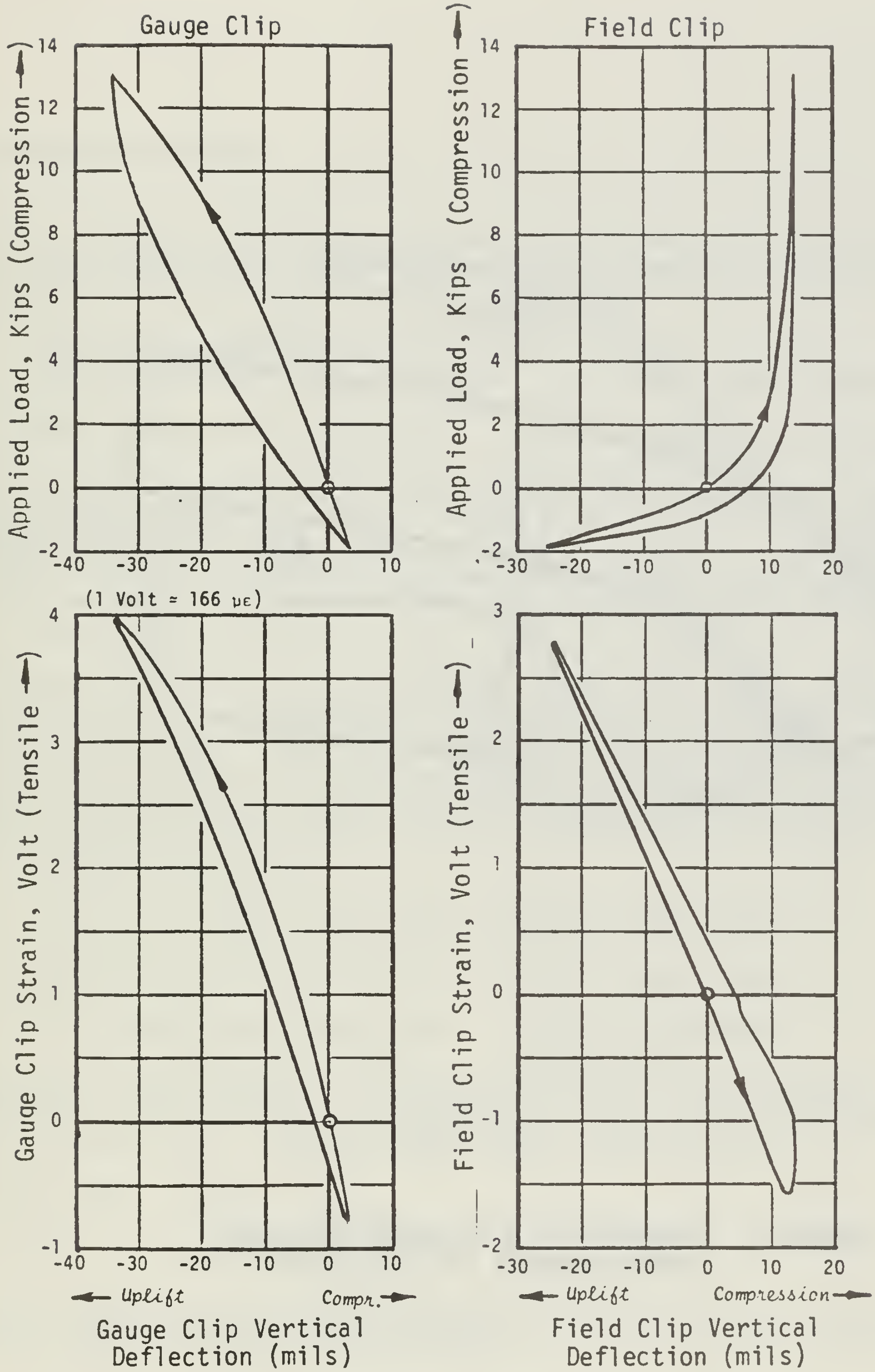


FIGURE 23. TYPICAL LOAD-DEFLECTION AND STRAIN-DEFLECTION PLOTS FROM FATIGUE TEST OF CONCRETE TIE FASTENER

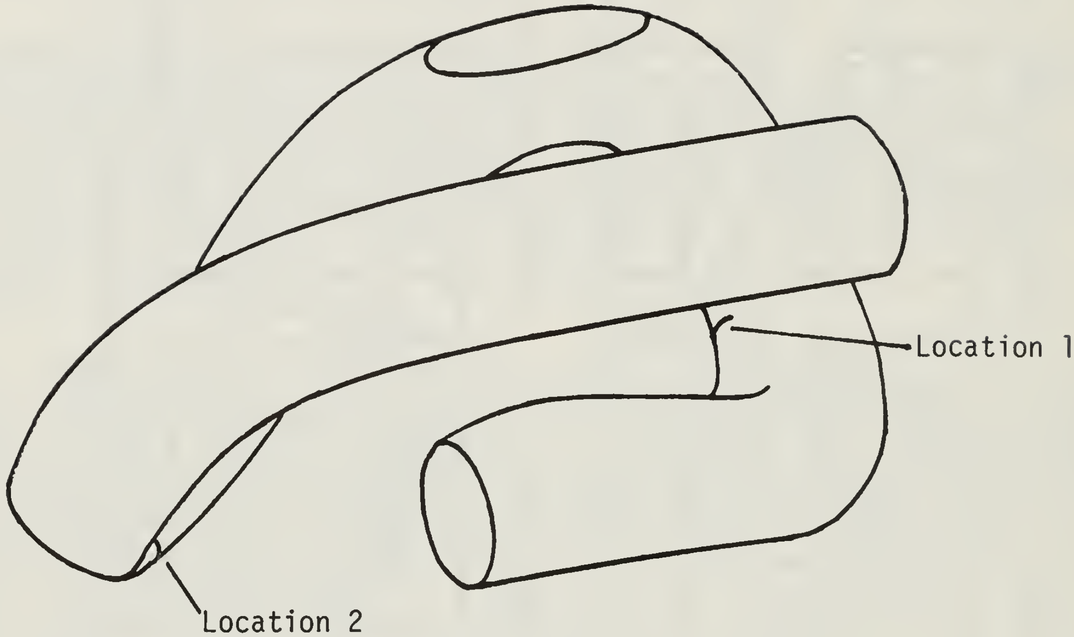


FIGURE 24. LOCATIONS OF CLIP CRACKS DEVELOPED DURING CONCRETE TIE FATIGUE TEST

Wood Tie Fastener Fatigue Test

Figure 25 shows the loading schematic for the wood tie fatigue test. The desired vertical deflections were relatively large compared to those for concrete tie track. The rail/tie deflection goals were:

a. Rail-to-tie vertical deflection at gauge and field clips: 0.100 inches peak-to-peak

b. Rail head lateral deflection: 0.100 inches peak-to-peak.

It was also necessary to induce most of the vertical deflection through bending of the tie plate rather than through flexing of the clips. A clip strain limit of about 1.5 volts had been seen in the track. A goal of 2 volts peak-to-peak (about 333 microinches/inch at the measurement location) was adopted to remain well below the strain limit of the clips (about 3.6 volts uplift strain above the installed strain).

Loading trials with the new tie block revealed that those deflection levels could not be reached within reasonable load limits without severely flexing the clips. This necessitated a partial adzing of the tie at the rail seat to reproduce the conditions observed in track, where most of the vertical deflection took place through flexing of the tie plate over the irregular surfaces of the service ties. The adzing was sufficient to produce the following conditions:

a. Field clip vertical deflection: 88 mils peak-to-peak

b. Gauge clip vertical deflection: 50 mils peak-to-peak

c. Rail head lateral deflection: 60 mils peak-to-peak.

This condition was adopted since it reproduced the essential phenomena of tie-plate bending at the field side. Greater deflections would have required significantly higher loads. The loads under these conditions were:

Compression: 16 kips

Uplift: 800 pounds.

As the test proceeded, the tie surface compressed and the deflections gradually increased to the following maximum values:

a. Field clip vertical deflection: 97 mils peak-to-peak

b. Gauge clip vertical deflection: 60 mils peak-to-peak

c. Rail head lateral deflection: 70 mils peak-to-peak.

The screw spikes required tightening about every 200,000 cycles.

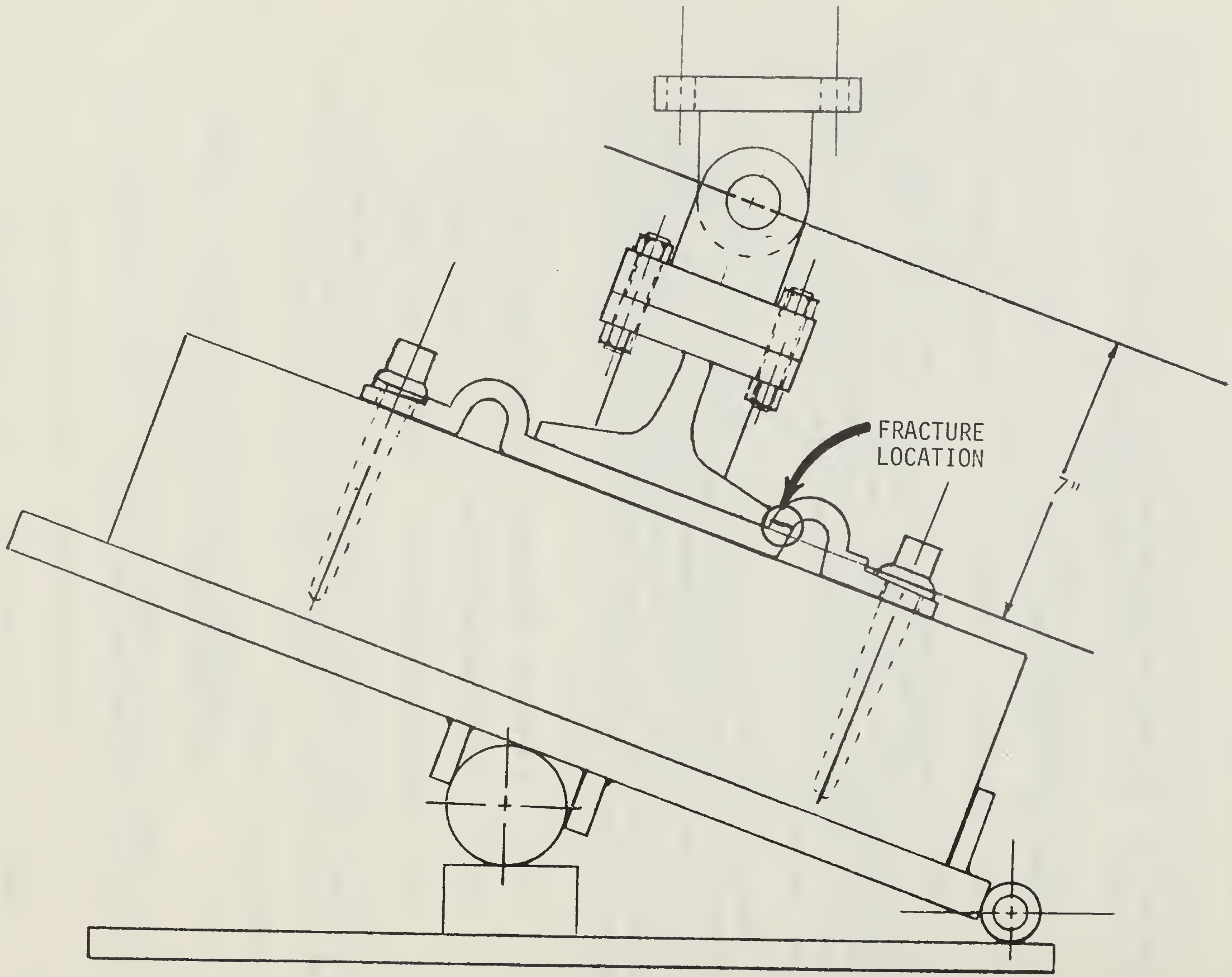


FIGURE 25. LOADING SCHEMATIC FOR WOOD TIE FASTENER FATIGUE TEST

The test was terminated at 1,090,000 cycles when it was discovered that the tie plate had fractured across its width at the location shown in Figure 25. This was the same type of failure which had occurred in service at FAST [4]. However, the test simulated only 36 MGT of traffic, while the plate failures began in track at 155 MGT. The partial adzing of the tie rail seat probably created more bending strain than occurred at FAST under the same deflection levels. The test represented loading events which occurred in track only a small percentage of the time, but was successful in reproducing two principal performance problems (plate fracture and spike loosening).

The plate used in this study has since been redesigned and strengthened where the fractures occurred. None of the redesigned plates has yet been tested at FAST.

DISCUSSION AND RECOMMENDATIONS

The results of this study have led to recommendations for modifications, deletions, additions or retention in current form of the AREA/Amtrak fastener system qualification tests listed in Table 1. The recommendations are presented and discussed as follows.

1. Fastening Insert Test

Retain in current form.

2. Fastening Uplift Test

The fastening uplift test provides a good indicator of the ability of the clips to absorb uplift load and to provide a continuous level of rail clamping force while flexing under train action. To better define fastener uplift capacity, the following changes are recommended:

a. Clip dimensional checks of the type illustrated in Figure 11 should be made before and after the test. Retention of the original clip dimension should be required within 0.005 inches.

b. The maximum uplift point should be specified in terms of an uplift displacement past pad separation, in a manner similar to the procedure of the current Amtrak test. The value of 0.050 inches uplift displacement is recommended. The tests under severe conditions at FAST revealed no requirement exceeding this value. In addition, the test should not proceed past the maximum load of 6000 pounds. This limit will prevent the bias of the test against rigid fasteners.

c. For each test run, the pad separation load should be determined as the mean of at least three successive trials. This mean load should not be allowed to vary more than 20 percent for measurements before and after the repeated loads tests, as is currently in the Amtrak series.

d. The current Amtrak test requires the measurement of an uplift spring rate which must fall within a specified range. Pad spring rate is of interest because it indicates the ability of the pad to absorb impact loads. However, there is no correlation between the relatively low uplift loads used to measure uplift spring rate and the ability of pad to absorb impact. It is recommended that this requirement for a uplift spring rate be deleted and that a requirement for a compressive spring rate, measured during the pad compression test, be substituted.

3. Fastening Repeated Loads Test

The results of this study show that the current repeated loads tests do not represent the worst fastener loading conditions identified on the FAST track. The AREA test is conducted at an L/V angle of 20 degrees and the Amtrak test involves an effective L/V angle of 18.4 degrees. The lateral restraint tests conducted as part of this study show that such angles produce rail head lateral deflections and vertical clip deflections much smaller than the maximum values found at FAST. It is recommended that the L/V angle of the repeated loads test be set to reproduce the maximum rail-to-tie deflections expected in service. The values used for the concrete tie fastener repeated loads test described in this report were 0.040 inches peak-to-peak vertical clip deflection and 0.100 inches peak-to-peak rail head lateral deflection. These deflections could be reproduced in either of the following ways:

a. Beginning with the nominal loads application of the Amtrak test, lower the vertical load until the maximum deflections reach the desired levels.

b. Beginning with the nominal loads application of the AREA test, raise the plane of incline of the fastener test fixture until the desired displacement levels are attained.

4. Fastening Longitudinal Restraint Test

The current longitudinal restraint test is adequate to establish the relative longitudinal resistance of fastener systems to thermal loading of unoccupied track. Some improvements in test procedures are needed. A requirement for two dial indicators [7] should be removed and replaced with a requirement for a displacement device accurate to 0.0005 inches and mounted on the centerline of the load actuator, at the opposite end of the test rail segment. To obtain this sensitivity, the limit of slip displacement should be defined at 0.10 inches, rather than at the current limit of 0.25 inches. The maximum longitudinal restraint load is normally obtained with a few mils of longitudinal displacement.

The longitudinal load should be applied to the point of slippage or to maximum load attainment, whichever requires the higher load. The current test stops at 2400 pounds. The extension will provide a factor for the relative evaluation of fastener systems.

Further study is needed of the effect of vibratory loading on the longitudinal restraint of fasteners. If vibratory loading changes the performance ranking of a representative selection of fasteners, then an independent test of longitudinal restraint under vibratory loading should be considered.

5. Lateral Load Restraint Test

This AREA test applies loads to the test rail segment at an L/V angle of 30 degrees. An initial load cycle to 20 kips removes the slack which may

exist between the rail base and the field side fastener shoulder. The first part of the test examines rail base lateral restraint by applying the vertical load through a wooden block to a maximum of 41 kips. This test is adequate to assess the structural integrity of the insulator and fastener shoulder.

The second part of the test examines the restraint of the fastener system to rollover displacement (difference between rail head and rail base lateral displacement). Rollers are used to eliminate any lateral restraint between the load actuator and the rail head. Rollover displacement is restricted to 1/4 inch under a load of 20.5 kips.

The results shown earlier in Figure 21 indicate that fasteners using flexible pads (static stiffness below about 1.4 million pounds per inch) may be unable to restrict the rollover displacement to the required 1/4 inch. The measurements at FAST indicated that rail head lateral displacements in track are a very weak function of pad stiffness. On the other hand, the initial displacements in the laboratory setup are a very strong function of pad stiffness, which controls rollover restraint until the upper corner of the rail base lifts off the pad. At this point the stiffness and strength of the clip begin to contribute significantly to rollover restraint. Thus, a flexible pad may require a stronger clip to meet the requirements of this test. Because the laboratory test shows a strong dependence of pad stiffness on rollover displacement while the track measurements do not, it is recommended that this test be deleted.

6. Tie Pad Load/Deflection Test

Recent discoveries of rail seat bending cracks in concrete ties installed on the Northeast Corridor and in several revenue service test segments have led to an investigation of the effect of pad stiffness on the levels of tie bending strain produced by impacts from wheel irregularities [9]. The study has provided several important conclusions:

a. Where ties are installed with rigid pads, the maximum tie bending strains produced by wheel irregularities on high-speed traffic can far exceed the levels required to cause rail seat bending cracks.

b. The occurence of crack-producing impact strain levels can be reduced or eliminated by major reductions in tie pad stiffness. For example, laboratory tests showed that a reduction in dynamically measured compressive pad stiffness from 5 million pounds per inch to 500,000 pounds per inch can attenuate maximum impact strains by 40 percent.

c. The compressive stiffness of some pad materials is significantly affected by the rate of load application.

On the other hand, it should be pointed that there are some loading environments where pad stiffness is not a major concern. Some ties on the FAST track have endured almost 600 MGT of heavy-haul traffic without cracking. The FAST track and train are regularly maintained, and the maximum speed of the train is 45 mph. Other test segments have been in revenue service for several years without significant cracking. Finally, there are some loading environments where cracked ties can remain in service for many years without impairment of function.

Cracked ties from the Kansas Test Track have seen almost 600 MGT of service at FAST without further deterioration.

Therefore, it is recommended that the selection of an appropriate tie pad stiffness for a given railroad application be based on a knowledge of the track loading environment. The selection should be based upon the frequency with which crack-producing wheel/rail loads or tie strains are expected to occur. Data for such determination will be available from current supporting investigations. Data from the Northeast Corridor track [15] contain the highest frequency of crack-producing tie strains yet found in U. S. revenue service. Bending strains above the level which can cause cracking at rail seats were found to occur at a typical site about 0.1 percent of the time. This represents an average frequency of occurrence of one event with the potential to produce a crack about every 1 to 2 days.

As a general guideline, it can be stated that the dynamically measured compressive stiffness of new tie pads should not exceed 1 million pounds per inch where any of the following conditions are expected to exist:

a. the speeds of normally maintained freight and passenger traffic will exceed 60 mph. "Normal" maintenance will permit advanced wheel irregularities to develop.

b. track defects such as severe engine burns exist.

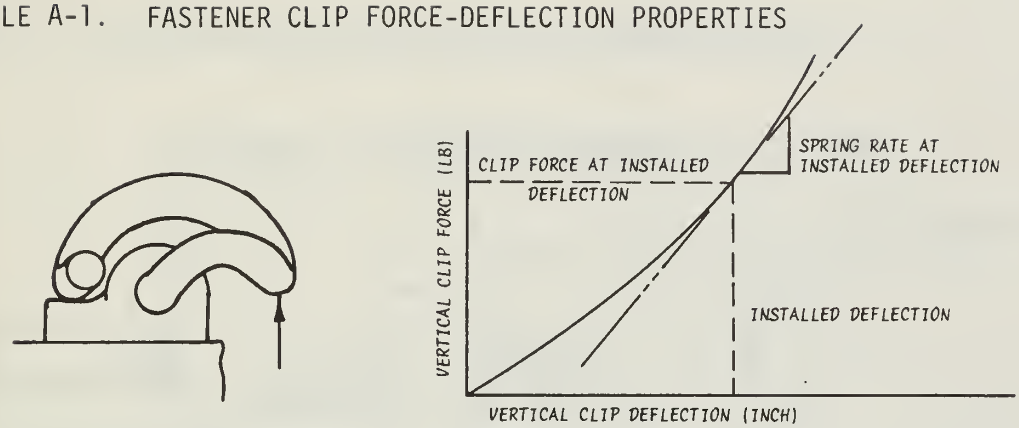
c. special track work (grade crossings, turnouts) may produce unusual dynamic loading.

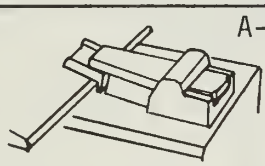
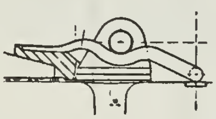
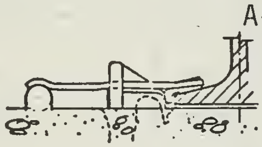
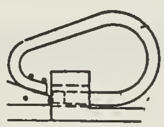
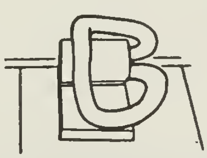
It is recommended that a guideline of this type be included in fastener qualification specifications, and that the dynamic compressive tie pad stiffness be included as part of tie pad load/deflection test.

APPENDIX A

DATA FROM EXISTING FASTENER PERFORMANCE TESTS

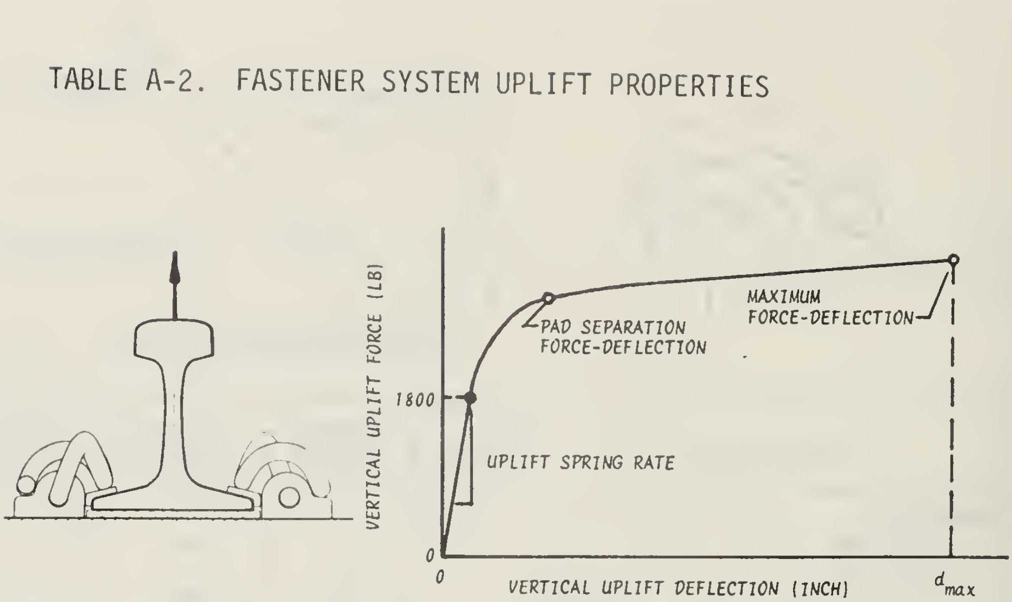
TABLE A-1. FASTENER CLIP FORCE-DEFLECTION PROPERTIES

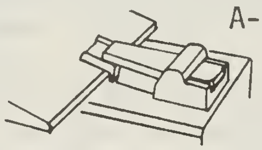
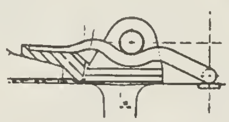
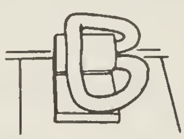


FASTENER CLIP TYPE	Data Source	INSTALLEO DEFLECTION (INCH)	CLIP FORCE AT INSTALLED OEFL. (LB)	SPRING RATE AT INSTALLEO OEFL. (LB/IN)
PANDROL 601A	A-1			
A. OESIGN CURVE		.590	2200	5640
B. QUALIFICATION TESTS				
INITIAL TESTS* - MEAN 		.598	2290	4840
RANGE		.562 - .637	1750 - 2780	3820 - 6120
FINAL TESTS* - MEAN		.590	1940	5160
RANGE		.570 - .637	1530 - 2350	3485 - 6980
HIXSON (QUALIFICATION TEST) 	A-2	.400	2800	7270
VSD (QUALIFICATION TEST)	A-3			
INITIAL TEST - MEAN		.449	2520	6800
RANGE 		.412 - .478	2250 - 2860	6580 - 7210
FINAL TEST - MEAN		.306	1425	5330
RANGE		.286 - .326	1270 - 1580	5240 - 5420
SPRINGLOCK (MANUF. OATA)	A-4			
CS3 CLIP 		.41	1700	4100 (Avg.)
CS5 CLIP		.41	2500	6100 (Avg.)
DE-SPRINGCLIP (MANUF. DATA)	A-4			
RANGE 		.394	1650 - 2650	4200 - 6720
RN - CLIP (MANUF. OATA) 	A-4	.157	1800	E1 = 2460 (< .161") E2 = 7480 (> .161")
SIDEWINOER (TEST OATA) 	A-5	No data	2042 - 2884	No data

*Between initial and final clip force-deflection tests, tie pad load-deflection, fastening uplift, longitudinal restraint, repeated loads, and push-pull tests were conducted.

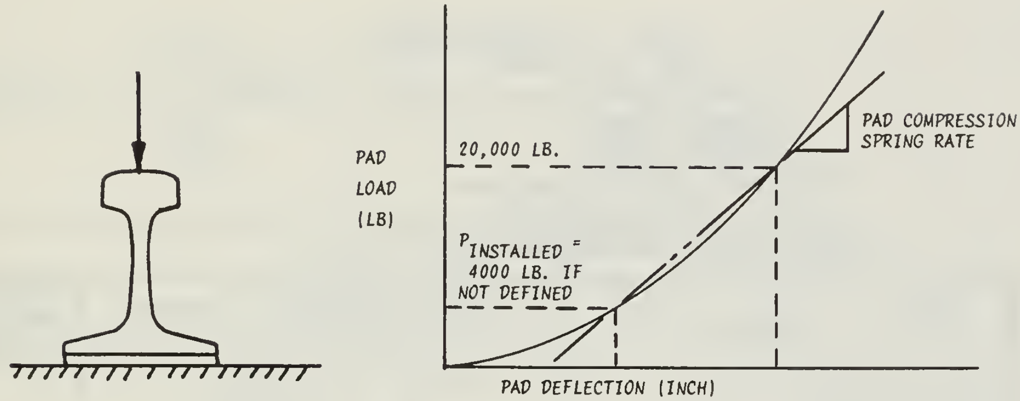
TABLE A-2. FASTENER SYSTEM UPLIFT PROPERTIES



FASTENER TYPE	Data Source	PAD SEPARATION FORCE (LB)	PAD SEPARATION DEFLECTION (INCH)	MAXIMUM FORCE (LB)	MAXIMUM DEFLECTION (INCH)	UPLIFT SPRING RATE (LB/IN)
PANDROL 601A / EVA PAD (QUALIFICATION TESTS)	A-1					
INITIAL TESTS* - MEAN		4830	.0172	6080	.1	2,310,000
FINAL TESTS* - MEAN 		4065	.0175	5370	.1	1,940,000
HIXSON / GROOVED RUBBER PAD 	A-2	4000-5400	.018-.042	8500	.17	235,000
VSD / 6 mm NEOPRENE PAD (QUALIFICATION TESTS)	A-3					
INITIAL TESTS* - MEAN		6860	.027	8690	.1	1,509,000
FINAL TESTS* - MEAN 		4290	.024	6745	.1	678,000
SIDEWINDER / POLYURETHANE PAD 	A-5	5545	No data	11,090	No data	No data

*Between initial and final uplift tests, longitudinal restraint, repeated loads and push-pull tests were conducted.

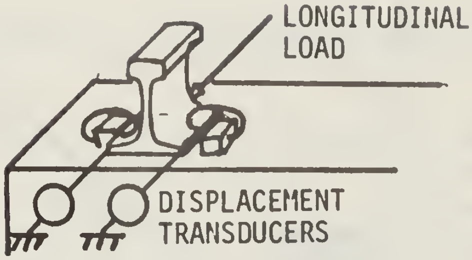
TABLE A-3. TIE PAD COMPRESSION LOAD-DEFLECTION PROPERTIES

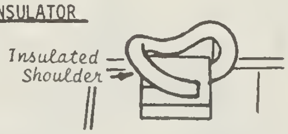
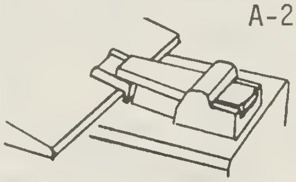
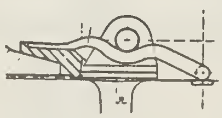
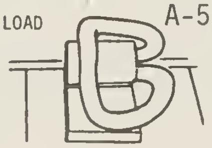
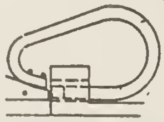


FASTENER TYPE	Data Source ↓	INSTALLED LOAD (LB)	INSTALLED DEFLECTION (INCH)	PAD SPRING RATE (LB/IN)
DUPONT VINYL EVA PAD (WITH PANDROL CLIP)	A-1			
INITIAL TEST* - MEAN		4915	.0033	3,700,000
FINAL TEST* - MEAN		4210	.0060	3,850,000
PANDROL TESTS (TO 4500 LB ONLY)	A-4			
POLYETHYLENE PAD		4000	.0020	4,100,000
FLAT NEOPRENE PAD		4000	.0051	2,800,000
GROOVED NEOPRENE PAD		4000	.0087	1,800,000
PANDROL SPECIFICATION (AT 20 METRIC TONS, BOUNDARY CURVES INTERSECT .4 and .8 mm)		4000 (ASSUMED)	.0034 - .0114	2,300,000 - 1,230,000
VSD/6 mm NEOPRENE PAD	A-3			
INITIAL TESTS* - MEAN		5180	.0214	865,000
FINAL TEST* (ONE TEST)		4000	.0220	770,000
MANUFACTURER'S DATA		4000 (ASSUMED)	.0044	825,000
SHINKANSEN DATA ENVELOPE	A-6	4000 (ASSUMED)	.0035 - .0112	740,000 - 840,000

*Between initial and final pad compression tests, fastening uplift, longitudinal restraint, repeated load, push-pull and rail clip load-deflection tests were conducted.

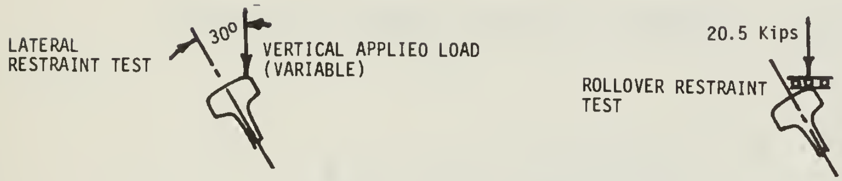
TABLE A-4. FASTENER LONGITUDINAL RESTRAINT PROPERTIES



FASTENER TYPE	*Data Source*	LONGITUDINAL LOAD (LB)	SLIPPAGE (INCH)	TOE LOAD BEFORE TEST (AVG. OF 2 CLIPS) (LB)
PANDROL 601A / EVA PAD 	A-1			
FASTENER SYSTEM 1 - INITIAL*		2400	.016	2370
- FINAL*		1690	CONTINUOUS	2150
FASTENER SYSTEM 2 - INITIAL		1620	CONTINUOUS	2350
- FINAL		1710	CONTINUOUS	2085
PANDROL 601A WITH EXTERNAL INSULATOR (Mean of 2 Tests)	A-7			
POLYETHYLENE PAD		3950	SLIP	- - -
FLAT NEOPRENE PAD		4000	SLIP	- - -
GROOVED NEOPRENE PAD		4000	SLIP	- - -
PANDROL 601A WITH INTERNAL INSULATOR (Mean of 2 Tests) 				
POLYETHYLENE PAD		3300	SLIP	- - -
FLAT NEOPRENE PAD		4950	SLIP	- - -
GROOVED NEOPRENE PAD		4650	SLIP	- - -
PANDROL 401 WITH EXTERNAL INSULATOR (Mean of 2 Tests)				
POLYETHYLENE PAD		3650	SLIP	- - -
FLAT NEOPRENE PAD		3700	SLIP	- - -
GROOVED NEOPRENE PAD		3650	SLIP	- - -
HIXSON / GROOVED RUBBER PAD 	A-2	2400	.020 - .024	2800
		3100	CONTINUOUS	
VSD / 6 mm NEOPRENE PAD 	A-3			
TWO INITIAL TESTS		2400	.038 - .0385	2100, 2940
TWO FINAL TESTS		1900, 2000	CONTINUOUS	1490 - - -
SIDEWINDER / POLYURETHANE PAD - MAX LOAD 	A-5	3100	START SLIP	- - -
DE SPRINGCLIP / MASONITE PAD (ON STEEL TIE PLATE & WOOD TIE) 	A-8			
MEAN OF 3 TESTS		3480	START SLIP	2200 (Nominal)
		3580	CONTINUOUS	

*Between initial and final longitudinal restraint tests, repeated loads, uplift, and push-pull tests were conducted.

TABLE A-5. FASTENER LATERAL RESTRAINT PROPERTIES



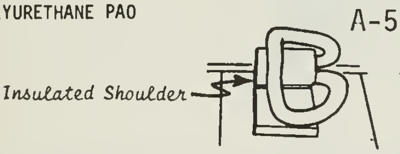
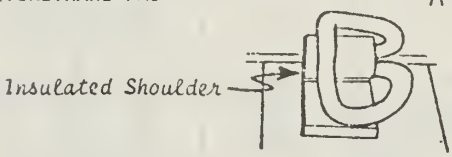
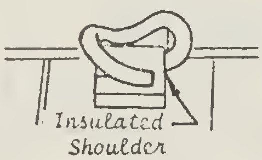
FASTENER TYPE	Data Source	VERTICAL APPLIED LOAD (KIPS)	LATERAL OEFLECTION AT GAGE HEIGHT (INCH)	BASE (INCH)	DIFFERENCE (INCH)
SIDEWINOER / POLYURETHANE PAO	A-5	41	- - -	.028	- - -
		20.5	.128	.014	.114
PANOROL 601A(1), 140 RE RAIL(2) (Mean of 2 Tests)	A-7				
EXTERNAL INSULATOR 					
POLYETHYLENE PAO		40	.103	.026	.077
FLAT NEOPRENE PAD		40	.376	.051	.325
GROOVEO NEOPRENE PAD		40	.494	.090	.405
INTERNAL INSULATOR 					
POLYETHYLENE PAO		40	.061	.014	.048
FLAT NEOPRENE PAD		40	.159	.018	.142
GROOVEO NEOPRENE PAO		40	.343	.002	.341
PANDROL 401(3), BS 113A RAIL(4) (Mean of 2 Tests)					
EXTERNAL INSULATOR					
POLYETHYLENE PAD		40	.075	.020	.055
FLAT NEOPRENE PAD		40	.139	.043	.096
GROOVED NEOPRENE PAO		40	.150	.044	.106
(1) 7/8" Oiameter Clip (2) 7 5/16" Height x 6" Rail Base Width (3) 13/16" Diameter Clip (4) 6.25" Height x 5.5" Rail Base Width					
CS-5 LEAF SPRING FASTENER (1971 British Tests, probably BS 113A rail)	A-7				
POLYETHELENE PAO		22.4(1)	.159	- - -	- - -
FLAT NEOPRENE PAO		38.1(2)	.197	- - -	- - -
" " "		51.5(3)	.29	- - -	- - -
GROOVEO NEOPRENE PAD		14 (4)			
(1) Test terminated due to spalling of concrete shoulder. (2) Crushing and spalling of concrete shoulder. (3) Test terminated due to equipment limitations and excessive gage widening. (4) Test terminated due to concrete shoulder failure					

TABLE A-6. FASTENER ROLLOVER RESTRAINT PROPERTIES

MAX LOAD = 20.5 KIPS

ROLLOVER RESTRAINT TEST

FASTENER TYPE	VERTICAL APPLIED LOAD (KIPS)	LATERAL DEFLECTION AT GAGE HEIGHT (INCH)	LATERAL DEFLECTION AT BASE (INCH)	LATERAL DEFLECTION AT DIFFERENCE (INCH)
SIDEWINDER / POLYURETHANE PAD - A-5 	20.5	.128	.014	.114
PANDROL 601A(1), 140 RE RAIL(2) (Mean of 2 Tests) A-7				
EXTERNAL INSULATOR 				
POLYETHYLENE PAD	20	.056	.017	.039
FLAT NEOPRENE PAD	20	.097	.022	.075
GROOVED NEOPRENE PAD	20	.148	.048	.100
INTERNAL INSULATOR 				
POLYETHYLENE PAD	20	.032	.009	.023
FLAT NEOPRENE PAD	20	.037	.011	.026
GROOVED NEOPRENE PAD	20	.081	.010	.071
PANDROL 401(3), BS 113A RAIL(4) (Mean of 2 Tests)				
EXTERNAL INSULATOR				
POLYETHYLENE PAD	20	.024	.007	.017
FLAT NEOPRENE PAD	20	.054	.026	.028
GROOVED NEOPRENE PAD	20	.070	.029	.041

(1) 7/8" Diameter Clip
(2) 7 5/16" Height x 6" Rail Base Width
(3) 13/16" Diameter Clip
(4) 6.25" Height x 5.5" Rail Base Width

APPENDIX B

STRAIN-VOLTAGE RELATIONSHIP OF INSTRUMENTED CLIPS

APPENDIX B

STRAIN-VOLTAGE RELATIONSHIP OF INSTRUMENTED CLIPS

Figure B-1 shows the schematic of the 4-arm bridge containing two active gauges and two completion resistors. Changes in resistance of the active gauges produce response e_o according to the equation

$$\frac{e_o}{e} = \frac{1}{4}\left[\frac{\Delta R_1}{R} - \frac{\Delta R_2}{R}\right] . \quad \text{(R = 120}\Omega\text{, nominal for all arms of bridge)} \tag{B-1}$$

The linear strain at each gauge is related to the fractional change in resistance of the gauge by

$$\frac{\Delta R_1}{R} = GF\ \varepsilon_1 , \quad \frac{\Delta R_2}{R} = GF\ \varepsilon_2 . \tag{B-2}$$

A ratio between ε_1 and ε_2 was established in laboratory tests conducted in preparation for the field measurements described in Reference [14]. For biaxial gauges placed at the position indicated in Figure B-1, it was consistently found that

$$\varepsilon_2 = -0.44\ \varepsilon_1 . \tag{B-3}$$

Thus an effective Poisson ratio of 0.44 was found. Substitution of (B-2) and (B-3) into (B-1) yields

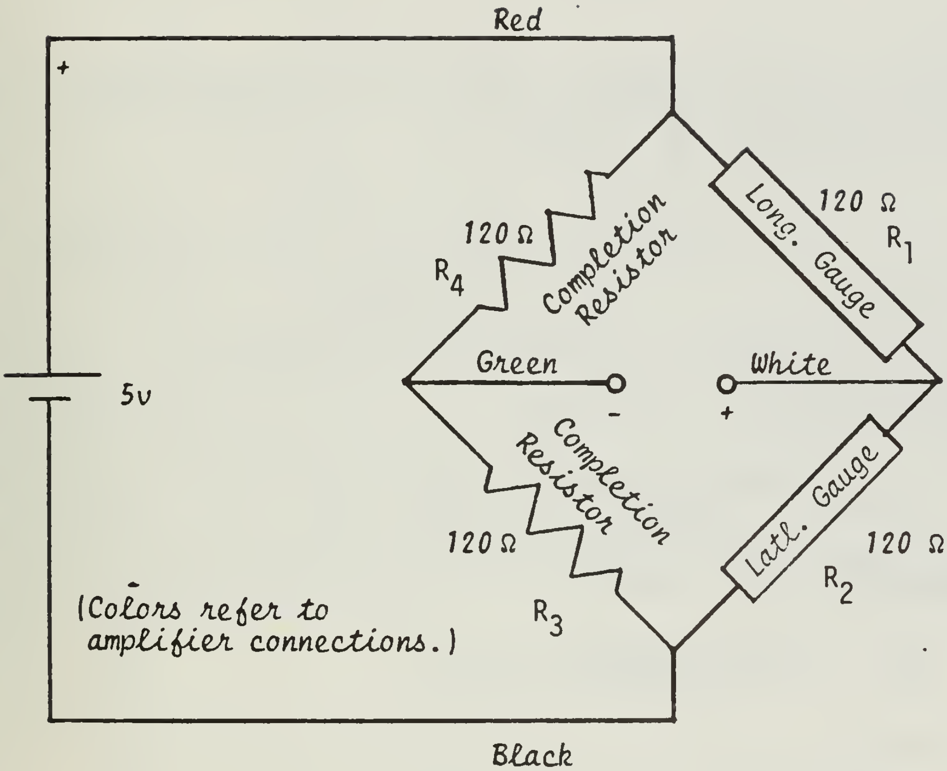
$$\frac{e_o}{e} = \frac{GF}{4}(1.44)\ \varepsilon_1 . \tag{B-4}$$

Shunt resistance R_c placed across two opposite arms of the bridge will produce the following ratio of response to excitation voltage:

$$\frac{e_o}{e} = \frac{1}{2}\frac{R}{R + R_c} .$$

Amplification of e_o yields

$$\frac{E_o}{e} = K\frac{e_o}{e} = \frac{K}{2}\frac{R}{R + R_c} . \tag{B-5}$$



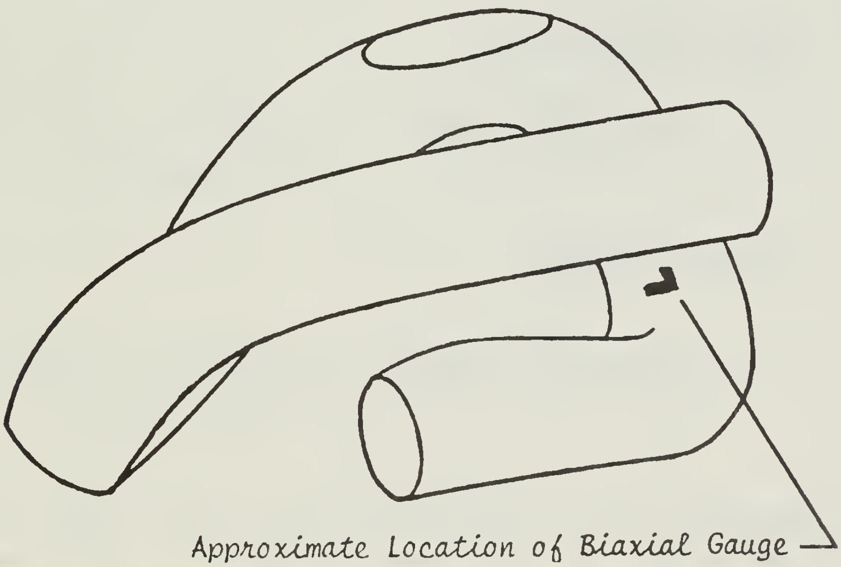


FIGURE B-1. SCHEMATIC OF TYPE A CLIP INSTRUMENTATION

Because the installation strain and dynamic strain were of such different magnitude, two separate shunt resistances were used. To determine K in each case, the amplification was adjusted so that

$$\frac{E_o}{e} = \frac{5}{5} = 1. \qquad \text{B-5}$$

Then the two amplification factors were determined as follows:

a. <u>Installation Strain</u>: $R_c = 24{,}900$

$$K_{inst.} = \frac{2(120 + 24{,}900)}{120} = 417. \qquad \text{B-5}$$

b. <u>Dynamic Strain</u>: $R_c = 100{,}000$

$$K_{dyn} = \frac{2(120 + 100{,}000)}{120} = 1670. \qquad \text{B-5}$$

Finally, the linear strain at Gauge 1 can be expressed in terms of output voltage as

$$\varepsilon_1 = \frac{4}{K\ GF\ (1.44)\ e}\ E_o \qquad \text{B-6}$$

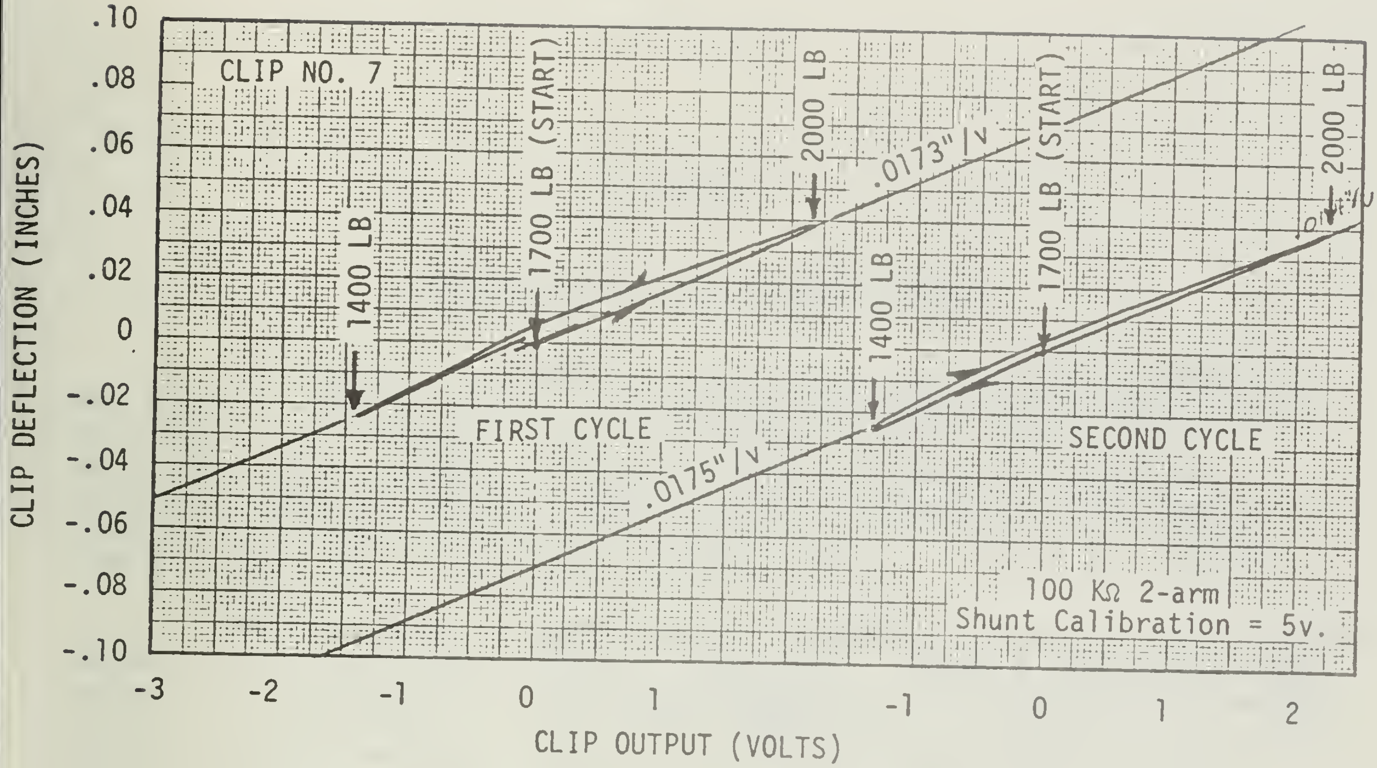
a. <u>Installation Strain</u>:

$$\varepsilon_1 = \frac{4}{(417)(2)(1.44)(5)}\ E_o = 0.000666\ E_o\ \text{(in/in)} \qquad \text{B-6}$$
$$= 666\ E_o\ (\mu\text{in/in}).$$

b. <u>Dynamic Strain</u>

$$\varepsilon_1 = \frac{4}{(1670)(2)(1.44)(5)}\ E_o = 0.000166\ E_o\ \text{(in/in)} \qquad \text{B-6}$$
$$= 166\ E_o\ (\mu\text{in/in}).$$

To determine the relationship between strain gauge bridge output and vertical clip deflection, the clips were subjected to the laboratory tests illustrated in Figure B-2. An arbitrary strain "zero" was established with a vertical clip load of 1700 pounds. The load was then cycled between 1400 and 2000 pounds. The slope of the curve of strain (volts) vs. deflection (inches) was reasonably linear and very consistent, as shown in the figure. The mean slope of the two clips illustrated is 0.0173 inches per volt, when the clips are given shunt calibrations equivalent to those applied for dynamic measurements in the field.



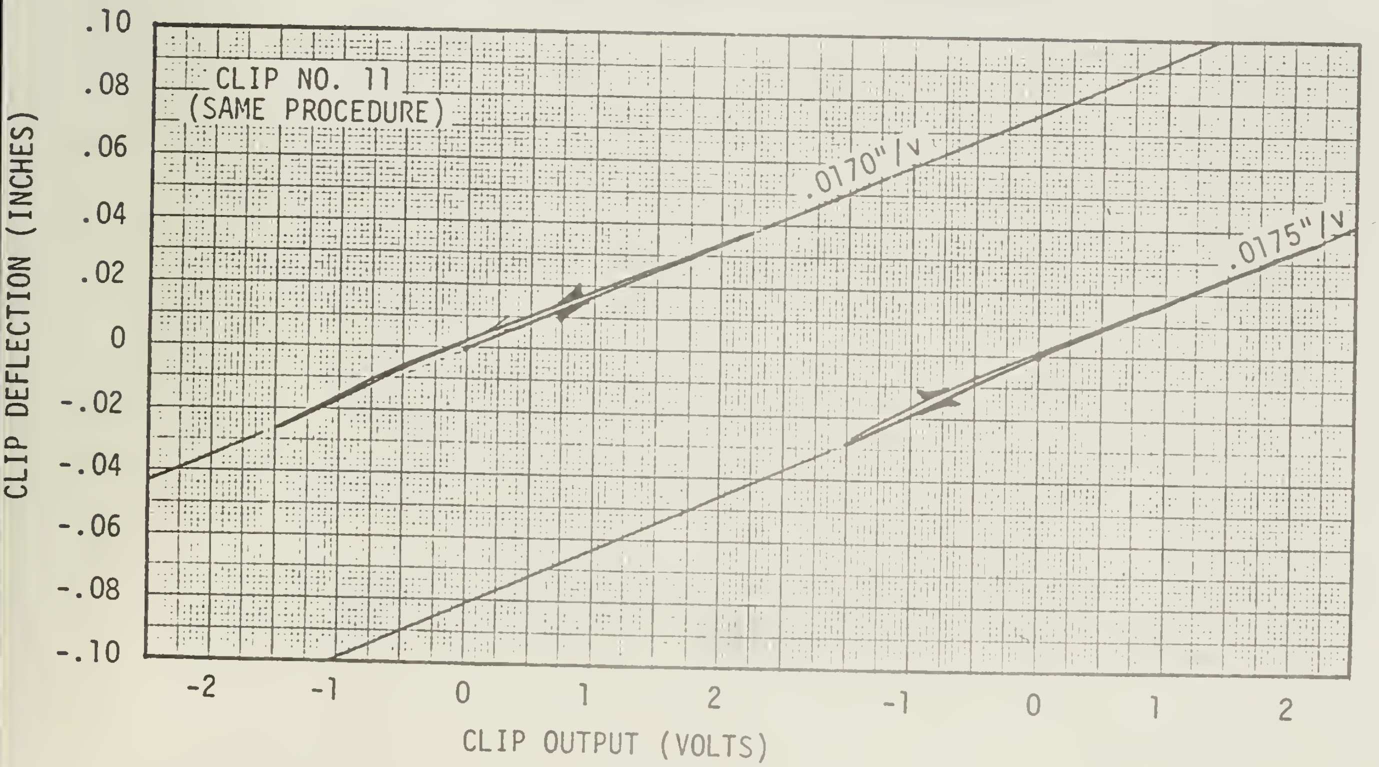


FIGURE B-2. MEASUREMENT OF CLIP RESPONSE VOLTAGE VS. DEFLECTION IN LABORATORY FIXTURE

APPENDIX C

LABORATORY TESTS OF INDIVIDUAL CLIPS

APPENDIX C

LABORATORY TESTS OF INDIVIDUAL CLIPS

The fixture illustrated in Figure C-1 was constructed to permit the measurement of vertical load-strain and load-displacement relationships of individual clips. Loading is applied through a vertical push rod which is supported by a ball bushing. The ball bushing was required to overcome friction created by a lateral component of the clip toe load. This lateral component is produced because the contact with the clip toe is made through a small segment of rail base which has slope of 1:4.

The fixture can be used with any combination of load cell and actuator. Deflection is measured with a DCDT as illustrated. Strain of the Type A clip was measured as described in Appendix B. The fixture is adaptable to a variety of clips by interchange of clip inserts. The stem of the insert passes through a slotted hole in the lower horizontal plate and is constrained by a ring containing set screws.

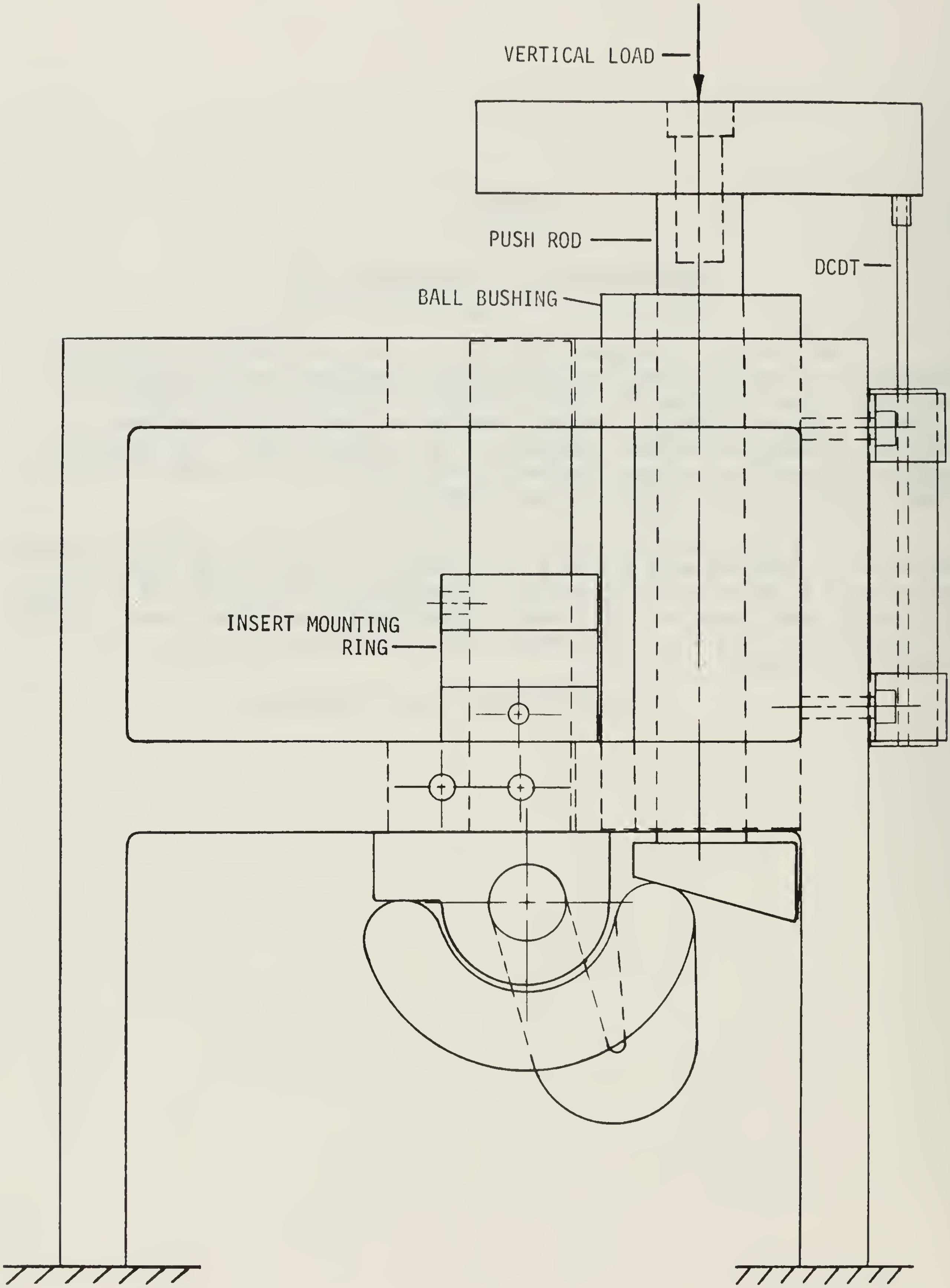


FIGURE C-1 FIXTURE FOR MEASUREMENT OF CLIP FORCE-DEFLECTION-STRAIN PROPERTIES

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